

VOLUME I

THE ROLE OF PLANT PRODUCTION IN SUBSISTENCE
AND CULTURAL CHANGES DURING THE FORMATIVE
PERIOD IN THE ATACAMA PUNA, SOUTHERN ANDES,
CHILE (1400BC-500AD).

A RE-EVALUATION BASED ON THE ANALYSES OF
MICROFOSSILS ATTACHED TO HOES AND GRINDING
TOOLS, AND ISOTOPIC ANALYSES OF HUMAN BONES.

Virginia McRostie Bustamante

PhD University College London

July 2013

ABSTRACT

The onset of agriculture is an important research topic in archaeology. Nonetheless, several areas of the world still lack sufficient datasets to participate critically within this debate. This is the case for the western slope of the Puna de Atacama, where explanations about plant production have been based on limited evidence resulting in assumptions about the role of agriculture associated with the Formative. More recent research in the Americas has acknowledged the diversity of developments taking place during the Formative period, including regional differences in the degree of wild and domestic plants food production. This research identifies and analyses new evidence in order to reevaluate current hypothesis and models of plant production in the Atacama. The analyses are based on the identification of plant microfossils taken from hoes and grinding tools and isotopes within human bones ($\delta^{13}\text{C}_{\text{col}}$, $\delta^{13}\text{C}_{\text{ap}}$, $\delta^{15}\text{N}$, $\delta^{18}\text{O}$, $\text{Sr}^{87}/\text{Sr}^{86}$). The result of these analyses argues that crops in the area were limited or absent and highlights different levels and managements for native plants such as *Scirpus*, Cactaceae and still unidentified tubers. Insights' regarding an anthropical origin of *Prosopis* forests and a silvo-pastoralist system provides a new model for the Formative of this arid highlands and the American continent.

Table of Contents Volume I

VOLUME I	1
ABSTRACT	3
Table of Contents Volume I	4
List of Figures Volume I	7
List of Tables Volume I	15
ACKNOWLEDGEMENTS	21
CHAPTER I. INTRODUCTION	23
The context for the onset of food production	23
Agriculture in the western slope of the Puna de Atacama	25
Research questions	30
Structure and brief outline of the thesis	30
CHAPTER II. THEORETICAL APPROACH	35
Introduction	35
II.1 A comparative review of the onset of agriculture	35
II.2 Perspectives for the western slope of the Puna de Atacama	46
Summary	55
CHAPTER III. The western slope of the Puna de Atacama. Ecological and cultural background	56
Introduction	56
III.1 Ecological Background	56

III.2 Archaeological Background	68
Summary	82
CHAPTER IV. Tracking the domestication and the entrance of crops in South America.	85
Introduction	85
Crop complexes	85
The High elevation Complex	88
The Mid elevation Complex	93
The Low elevation Complex	98
Non-indigenous pre-Columbian plants.....	109
Summary	118
CHAPTER V. Foodways on the western slope of the Puna de Atacama. An evaluation with emphasis on plants.	120
Introduction	120
V.1 Plants.....	122
V.2 Technologies associated with plants	141
V.3 Animals in subsistence	153
V.4 Bio-anthropological data.....	155
Summary	169
CHAPTER VI. Contextualising the sites sampled.....	172
Introduction	172
VI.1 Middle Loa	175

VI.2 Salar de Atacama area	182
Northern area	182
Southern area	195
Summary	207
CHAPTER VII. METHODOLOGY.....	209
Introduction	209
VII.1 Microfossil reference collection, archaeological sampling and microfossil characterization	209
VII.2. Isotopes: Principles, reference collection and archaeological samples .	224
Summary	233
CHAPTER VIII. RESULTS	235
Introduction	235
VIII.1 Microfossils.....	235
VIII.2 Isotopes	290
Summary	308
CHAPTER IX. DISCUSSION New perspectives about the role of plant production in the Formative changes of the western slope of the Puna de Atacama	311
Introduction	311
IX.1 Answering the research questions	312
IX.2 An alternative model for the western slope of the Atacama Puna Atacama and Formative human-plant interactions	362
IX.3 Methodological and future issues	371

CHAPTER X. CONCLUSION	375
Final remarks.....	375
Future Research	381
References	384

List of Figures Volume I

Figure 1. Stages and methods of plant food production. Reproduced from Ford (1985, 2).	39
Figure 2. Classificatory and evolutionary model of plant-food yielding systems. Reproduced from Harris (1989, 17).	40
Figure 3. Conceptual development map of the middle ground between hunting-gathering and agriculture. Reproduced from Smith (2001b, 15).	41
Figure 4. Western slope of the Puna de Atacama. Study area hatched. Adapted from (Cartajena <i>et al.</i> 2007, 158).	57
Figure 5. Geographical floors in the Atacama Puna. Adapted from (Dransart 2002, 171).	58
Figure 6. Oases, ravines, rivers and meadows ecosystems (courtesy of Eduardo Lira).	58
Figure 7. Subareas (Loa River / Salar de Atacama hatched) and ecosystems (oases, meadows, rivers/ravines) studied. Adapted from Latorre <i>et al.</i> (2003, 226).	60
Figure 8. Diagram of vegetation belts. Adapted from Latorre <i>et al.</i> (2003, 227).	61
Figure 9. Late Archaic sites sampled for this thesis. Adapted from Latorre <i>et al.</i> (2003, 226)	71

Figure 10. Early Formative sites sampled for this thesis. Adapted from Latorre <i>et al.</i> (2003, 226).	75
Figure 11. Middle and Late Formative sites sampled for this thesis. Adapted from Latorre <i>et al.</i> (2003, 226).....	81
Figure 12. Map showing major localities and sites named in this chapter. Adapted from Horta (2012, 8).	121
Figure 13. Conical mortar Kalina and flat mortar Tulan 122.....	143
Figure 14. Ethnographic hoes in the San Pedro oases. Reproduced from Bittman <i>et al.</i> (1978, 49).....	146
Figure 15. Lithic hoe offered in a tomb of Chorrillos. Below the blade, wood remains suggest a handle stick (courtesy of F. Martinez).	147
Figure 16. Starch grain found on lithic hoe Tulan 55 estrato 3. Reproduced from McRostie (2007, 47).....	148
Figure 17. Chronology, location and ecosystem of the sites sampled. Adapted from Latorre <i>et al.</i> (2003, 226).....	173
Figure 18. Loa riverside.	177
Figure 19. Kalina site.	177
Figure 20. Ranl 273-A. Reproduced from (Pollard 1971, 45).	179
Figure 21. Conical mortars in Puripica 1. Reproduced from (Núñez <i>et al.</i> 1999, 168).	184
Figure 22. Puripica 1 plant and profile. Reproduced from (Núñez <i>et al.</i> 1999, 167).	184
Figure 23. Plan of village Puripica 23. Reproduced from Núñez (2005, 176).	186
Figure 24. Vilama River from Ghatchi site.	187

Figure 25. Ghatchi site. Reproduced from Adán & Urbina (2007, 20).	188
Figure 26. Formative structures Ghatchi 2C. Figure 27. Exhausted mortar in structure.	189
Figure 28. Calar village. Reproduced from (Adán & Urbina 2007, 18).	191
Figure 29. Tulor 1. Reproduced from (Adán & Urbina 2007, 14).	194
Figure 30. Toconao Oriente site. Reproduced from Le Paige (1973, 170).....	196
Figure 31. Tulan ravine and major sites. Reproduced from (Núñez <i>et al.</i> 2006, 94).	197
Figure 32. Plan view Tulan 122, residential structures. Courtesy of F. Gutierrez. ..	199
Figure 33. Tulan 54 Temple. In the sterile floor are visible the holes for the newborn burials. Reproduced from Núñez <i>et al.</i> (2002-2005).	201
Figure 34. Types of burial at Tulan 58. Reproduced from (Núñez <i>et al.</i> 2006, 108).	202
Figure 35. Plan of Tulan 57 village. Reproduced from Núñez (2005, 107).	205
Figure 36. Plan of Tulan 82 village. Reproduced from Núñez (2005, 186).	206
Figure 37. Distribution of artefacts sampled per period (LA: Late Archaic, E.F: Early Formative; L.F: Late Formative; F: Formative -represents all the Formative sub-periods-).	213
Figure 38. Distribution of types of artefacts sampled.	213
Figure 39. Types of microfossils on artefacts (ph: phytoliths, sg: starch grains, d: diatoms, p: pollen, sp: spherulites, ox: oxalates).	236
Figure 40. Long psilate cells with varied borders.	238
Figure 41. Rondels.	239

Figure 42. Cross shape.	240
Figure 43. Bulliform cells including cf. <i>Phragmites</i> – b and reeds – c.	241
Figure 44. Rod cells cf. Cyperaceae (a-f) v/s ashes (g-i).	242
Figure 45. Cones cf. Cyperaceae.	243
Figure 46. Long cells cf. Reeds.	243
Figure 47. Trichomes.	244
Figure 48. Hair cells.	244
Figure 49. Tracheids.	245
Figure 50. <i>Opuntia</i> sp. spherical phytoliths.	246
Figure 51. Dicotyledon phytoliths.	247
Figure 52. Non-identified phytoliths.	248
Figure 53. Non-identified starch grains.	250
Figure 54. Cf. <i>Prosopis</i> sp. 1 starch grains.	251
Figure 55. Cf. <i>Prosopis</i> sp. 2 regular starch grains.	252
Figure 56. <i>Prosopis</i> sp. 2 irregular starch grains.	252
Figure 57. Cf. <i>Zea/Prosopis</i> starch grains.	254
Figure 58. Cf. <i>Geoffroea decorticans</i> starch grain.	255
Figure 59. Cf. Tuber-type starch grains.	257
Figure 60. Cf. <i>Hoffmannseggia</i> sp. starch grains.	258
Figure 61. Cf. Cucurbitaceae starch grains.	259
Figure 62. Cf <i>Capsicum</i> starch grain.	260

Figure 63. Cf. Cyperaceae starch grains.	261
Figure 64. Ambiguous agglomerates.	261
Figure 65. Calcium oxalates.	262
Figure 66. Diatoms.	263
Figure 67. Pollen.	263
Figure 68. Camelid spherulites.	264
Figure 69. Artefacts with presence of phytoliths considered most likely to be the product of natural formation process (LA: Late Archaic, E.F: Early Formative; L.F: Late Formative; F: Formative -represents all the Formative sub-periods-).	265
Figure 70. Artefacts with presence of phytoliths considered as cultural (LA: Late Archaic, E.F: Early Formative; L.F: Late Formative; F: Formative -represents all the Formative sub-periods-).	266
Figure 71. NI (not identified) and Chenopodiaceae starch grains (LA: Late Archaic, E.F: Early Formative; L.F: Late Formative; F: Formative -represents all the Formative sub-periods-).	267
Figure 72. Presence of diatoms on sites and artefacts.	271
Figure 73. Artefacts with presence of spherulites per site and periods (E.F: Early Formative, L.F. Late Formative).	273
Figure 74. Similar taxa between different museums.	274
Figure 75. Number of artefacts with cultural microfossils per site and period (LA: Late Archaic, E.F: Early Formative; L.F: Late Formative; F: Formative -represents all the Formative sub-periods-).	277
Figure 76. Artefacts with presence of different “cultural” microfossils (sg: starch grains; ph: phytoliths; sp: spherulites; ox: oxalates).	278

Figure 77. Presence of different taxa on artefacts according to the different microfossils (ox: oxalate, sp: spherulite, sg: starch grain, ph: phytolith).	279
Figure 78. Presence of plants categories (domestic, uncertain, wild) on artefacts.	280
Figure 79. Types of microfossil and taxa present on hoes or grinding tools (ox: oxalates; ph: phytoliths; sg: starch grains; sp: spherulites).	281
Figure 80. Distribution of taxa on hoes from different sites and periods (E.F: Early Formative; L.F: Late Formative; F: Formative- represents all the Formative sub-periods-).	282
Figure 81. Distribution of taxa on grinding tools during the Late Archaic and during the Formative period: E.F: Early Formative, L.F: Late Formative, F: Formative - represents all the Formative sub-periods-).	283
Figure 82. Taxa identified on conical mortars from Late Archaic (L.A.) sites.	284
Figure 83. Presence of taxa on artefacts from sites- and their respective ecosystem location - (E.F: Early Formative, L.F: Late Formative and F: Formative represents all the Formative sub-periods).	285
Figure 84. Presence of taxa on artefacts within the Formative sequence (EF: Early Formative, L.F: Late Formative and F: Formative -represents all the Formative sub-periods).	285
Figure 85. Distribution of <i>Prosopis</i> on artefacts from Formative sites (EF: Early Formative, L.F: Late Formative and F: Formative -represents all the Formative sub-periods).	286
Figure 86. Distribution of tuber types on artefacts from Formative sites (L.F: Late Formative and F: Formative -represents all the Formative sub-periods).	287
Figure 87. <i>Solanum</i> type found in Chorrillos.	287
Figure 88. Crops present on artefacts from Formative sites (L.F: Late Formative and F: Formative -represents all the Formative sub-periods).	288

Figure 89. Plant categories (wild, domestic, uncertain) through periods (L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative; F: Formative represents all the Formative sub-periods).....	289
Figure 90. Plant taxa in relation to the ecosystem of the sites where they were found.	290
Figure 91. $\delta^{13}\text{C}\text{‰}$ and $\delta^{15}\text{N}\text{‰}$ reference baseline.	293
Figure 92. Mean values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for archaeological individuals.	297
Figure 93. $\delta^{13}\text{C}_{\text{col}}$ correlated to $\delta^{15}\text{N}$	298
Figure 94. $\delta^{13}\text{C}_{\text{ap}}$ correlated to $\delta^{13}\text{C}_{\text{col}}$	299
Figure 95. $\delta^{15}\text{N}$ correlated to $\Delta^{13}\text{C}_{\text{col}}$	300
Figure 96. +9.4 model for apatite fractionation.	302
Figure 97. +12 model for apatite fractionation.	302
Figure 98. +5.1 model for collagen fractionation.	303
Figure 99. Mean values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ per site.	307
Figure 100. Individual values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$	308
Figure 101. Presence of taxa on artefacts by sites and periods. L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).....	313
Figure 102. Presence of microfossil taxa by periods. L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).	314
Figure 103. Presence of cacti, <i>scirpus</i> and tuber types microfossils through the whole sequence. L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).....	320

Figure 104. Presence of <i>Prosopis</i> in Formative sites and their ecosystems. E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).	322
Figure 105. Categories (domestic-crops-, wild, uncertain) of plants in L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).....	331
Figure 106. Resources versus ecosystem site location.....	332
Figure 107. Presence of taxa on artefacts from sites located in oases, meadows and ravines.	333
Figure 108. Sites where hoes were sampled.....	337
Figure 109. Presence of different taxa on hoes: E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).....	340
Figure 110. Sites where spherulites were recovered from hoes E.F: Early Formative; L.F: Late Formative.....	342
Figure 111. Category and taxa of plants on grinding tools in L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).....	345
Figure 112. Presence of taxa on <i>manos</i> and mortars during the Late Archaic (A) and Formative (F).	346
Figure 113. Taxa on grinding tools by time and sites. L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).	348
Figure 114. $\delta^{13}\text{C}$ mean values for sites.	358
Figure 115. $\delta^{13}\text{C}$ values by individual in sites.....	358

Figure 116. Taxa in sites regarding their locality and period L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).....	360
---	-----

List of Tables Volume I

Table 1. Risk-spreading strategies with some Andean examples (Browman 1987b, 2).	47
Table 2. Different ecological belts and main resources from the coast to the highlands.	64
Table 3. Local phases and their chronological, cultural and spatial characteristics (*See Table 2 for ecosystem characterization).	69
Table 4. Denomination for different phases of the Formative period in different areas.....	72
Table 5. The three phytogeographical zones in which the roots and tuber crops of the American tropics originated. Reproduced from Hawkes (1989, 484).	86
Table 6. Proposed areas of origin of major South American cultivated plants. Reproduced from Pearsall (1992, 193).	87
Table 7. Normalised dates (BP) for the appearance of High Complex tubers (sg: starch grain).....	90
Table 8. Normalised dates (BP) for the appearance of High Complex pseudocereals (sg: starch grain).	92
Table 9. Normalised dates (BP) for the appearance of Middle Complex beans (sg: starch grain).....	94

Table 10. Normalised dates (BP) for the appearance of Middle Complex <i>Arachis</i> (sg: starch grain).....	96
Table 11. Normalised dates (BP) for the appearance of Middle Complex pseudocereals, fruits and tubers (sg: starch grain).	97
Table 12. Normalised dates (BP) for the appearance of Middle Complex <i>Erythroxylon coca</i>	98
Table 13. Normalised dates (BP) for the appearance of Low Complex tubers (sg: starch grain, phyto: phytolith).....	102
Table 14. Normalised dates (BP) for the appearance of Low Complex <i>Capsicum</i> (sg: starch grain).....	103
Table 15. Normalised dates (BP) for the appearance of Low Complex <i>Gossypium</i>	105
Table 16. Normalised dates (BP) for the appearance of Low Complex <i>Cucurbita</i> (sg: starch grain, phyto: phytolith).....	109
Table 17. Normalised dates (BP) for the appearance of non-indigenous pre-Columbian plants <i>Lagenaria</i> (sg: starch grain, phyto: phytolith).....	111
Table 18. Normalised dates (BP) for the appearance of “non indigenous crops” <i>Zea mays</i> (sg: starch grain, phyto: phytolith).	117
Table 19. Crop presence (micro and macro evidences) in Atacama Puna and neighbouring areas.	119
Table 20. Foodways and seasonal availability of local edible traditional plants. ...	136
Table 21. Main sites, phases, ecosystems, technologies and crops (L.A: Late Archaic, E.F: Early Formative, L.F: Late Formative; semi: semi-permanent, cem: cemetery, perm: permanent).	153
Table 22. Daily caloric requirements per individual based on Palaeolithic models.	156

Table 23. Kilocalories from main edible resources based on different references (from highest to lowest).....	159
Table 24. Reference guideline $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ Atacama plants.	165
Table 25. $\delta^{13}\text{C}_{\text{col}}$ values for Tulan camelids. Reproduced from López (2010, 132).	166
Table 26. Sites and samples (L.A: Late archaic, E.F: Early Formative; F: Formative; L.F: Late Formative; S.A: Salar de Atacama).....	175
Table 27. Sites and artefacts sampled (LA: Late Archaic, E.F: Early Formative; L.F: Late Formative; F: Formative -represents all the Formative sub-periods-).....	212
Table 28. Taphonomical consequences related to culinary practices. Number of crosses is correlated with degree of damage. Reproduced from Babot (2007, 108) translated by V. McRostie.	223
Table 29. Plant specimens collected for the reference collection ($\delta^{13}\text{C}/\delta^{15}\text{N}$).	228
Table 30. Archaeological individuals sampled for different isotopes.	230
Table 31. Archaeological samples for $\delta^{13}\text{C}_{\text{ap}}$ and $\delta^{18}\text{O}$	231
Table 32. Archaeological samples for $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$	232
Table 33. Archaeological samples for $^{87}\text{Sr}/^{86}\text{Sr}$ isotopes.	233
Table 34. Presence of different phytoliths on artefacts and identification level assigned (P: presence).	237
Table 35. Starch grains presence and identification.	249
Table 36. <i>Zea mays</i> versus <i>Prosopis</i> starch grains in my own and others' reference collections (See Appendix 3 and 4) (P: Present/ A: Absent).	253
Table 37. Association to macro-remains (CH: charred/ NCH: not charred/ ?: not mentioned in the original.....	268

Table 38. Oxalates presence on sites and tools.	270
Table 39. Diatoms: association with artefacts	272
Table 40. Comparative table of macroremains and microremains (see also Table 21).	275
Table 41. Breakdown of the artefacts sampled by period and the presence of cultural and non-cultural microfossils (C: column; A: artefact).	277
Table 42. $\delta^{13}\text{C} +1.5$ carbon industrial effect added to modern samples and $\delta^{15}\text{N}$ values for local plants.	292
Table 43. Calculated from the samples' $\delta^{13}\text{C}$ values, $+1.5\text{‰}$ carbon industrial effect added to contemporary samples, -2‰ subtracted from bone samples to estimate animal flesh and $+3\text{‰}$ added to $\delta^{15}\text{N}$ for trophic-level effect. Adapted from (Tykot et al. 2009, 163).	293
Table 44. Theoretical model of C3/C4 plant consumption base in the average of C3/C4 local plants and isotopic diet with $+5.1$, $+9.4/+12$ fractionation models. Adapted from Tykot (2009, 165).	294
Table 45. $\delta^{13}\text{C}_{\text{Cap}}$, $\delta^{13}\text{C}_{\text{Col}}$, $\delta^{15}\text{N}_{\text{Col}}$ values for 21 individuals sampled (no: no tissue available; values represents the average for each individual).	296
Table 46. Collagen-apatite spacing models for C3/C4 dietary components. Reproduced from Tykot <i>et al.</i> (2009, 161).	299
Table 47. % of C4 plants for each individual using different fractionation models.	301
Table 48. Archaeological values of $^{87}\text{Sr}/^{86}\text{Sr}$ isotopes.	304
Table 49. $\delta^{18}\text{O}$ values for archaeological samples.	305
Table 50. Density of camelid bones in three Archaic sites. Adapted from (Núñez & Santoro 1988, 58).	352

Table of Contents

VOLUME II	454
APPENDIX 1. Chronology of early crops in South America	456
APPENDIX 2. Contexts of the samples	477
2.1 Middle Loa	
2.2 Salar de Atacama	
Northern area	
Southern area	
APPENDIX 3. Microfossil reference collection	497
I. STARCH	
II. PHYTOLITHS	
DICOT	
MONOCOT	
APPENDIX 4.1 Starch variants protocol	579
APPENDIX 4.2 Starch variants in reference collection	583
APPENDIX 5. Sampling of starch in gloves	611
APPENDIX 6. Archaeological microfossils database	613
APPENDIX 7. Archaeological Isotope samples	634

ACKNOWLEDGEMENTS

The list of persons who support these four years of research in multiple ways is large.

Overall I am grateful to the descendants of those who build the history I am working with.

To my family, Fernando, Amelia and Joaquin; for their encouragement, understanding, love and patient as well the joy and challenges they gave me.

To my parents, Peter and Bernardita, for believe in me and support me along the way; also to my brothers Paul, Felipe and Cristobal for being there and here. To my lovely aunt Anita and perspective of life.

To my “UK” friends, especially to Fernanda Kalazich, Javiera Atenas, Isabel Rivera, Sophia Laparidou, Paula Gutierrez and MJose Becerra as well the worldwide community of Nansen Village with whom I share this life time experience. To the founders and the administration team of Nansen Village which make possible to live on an oasis in the middle of London, making life smooth for students, especially the ones with toddlers. Also to Rainbow nursery, their manager Claudia Olivera and staff, for look after my babies and help me to gain time within this mother-student job.

To my UK professors and advisors, Arlene Rosen and Bill Sillar which advice me and support me through my entire thesis as well to Manuel Arroyo who joined me later but with wise advice.

To other professors and staff of UCL as Sandra Bond, Michele Wollstonecroft, Dorian Fuller, Jose Olivera, Alison Weisskopf, Lisa Daniel, Liz Henton, Dorinda Ostermann and many more that in some way or another help me.

To CONICYT Becas Chile to give me the opportunity to carry on this PhD and to UCL graduates funding which support my fieldwork. To Christine Hastorf and Lautaro Núñez which recommend me to UCL. Also to Doctor Jane Evans and NERC Isotope Geosciences Laboratory which support a pilot study for Sr isotopes.

To all my Chilean colleagues which at some point help me with their knowledge, advice or other issues:

María Teresa Planella, Fernanda Falabella, Victoria Castro, Isabel Cartajena, Lorena Sanhueza, Fernanda Kalazich, Carolina Belmar, Luciana Quiroz, Carolina Agüero, Felipe Martínez, Patricio López, Claudio Latorre, Antonio Maldonado, Julio Kalazich, Francisca Santana, M Jose Duarte, Carlos González, Francisco Gallardo, Emily Stovel, Mark Hubbe, Érica Díaz, Ximena Novoa and Omar Reyes.

And for those international colleagues especially Pilar Babot, Alejandra Korstanje, Verónica Lema, Penelope Dransart, Jaime Pagan; also to Michael Chapman, Mark Druss, Gordon Pollard, Tiago Hermegenildo and Don Matesz.

CHAPTER I. INTRODUCTION

The context for the onset of food production

The Neolithic as defined for the Old World has greatly influenced the characterisation of worldwide societies with similar components. These include some kind of food production, sedentary villages, growing hierarchisation with its corollaries at the material cultural level, and technological innovations such as pottery. Regarding the causes of the shift to food production, the most commonly used explanations are food stress models that identify demographic pressure, environmental change or social competition as primary reasons (Bender 1978; Binford 1968; Childe 1951; Cohen 1977; Flannery 1969; Hayden 1990; 1995; Wright, H.E. 1993). These features inspired archaeologists investigating Northern and South America from the first half of the twentieth century to find parallels with the Neolithic of the Old World rather than with the specificities of the American contexts (2006, 36). Hence in the Americas the Formative period was defined as cultures that “possess the technologies of pottery, weaving, and developed food production. Social organisation is supposed to involve permanent towns and villages, as well as the first ceremonial centres. Ideologically, an early priestly class or theocracy is often present or in development” (Willey & Phillips 1958, 144). Within this definition, the presence of maize and/or manioc agriculture was a main component in the shift from predator to producer and the development of a successful sedentary life. “This is a parallel to Childe’s definition for the beginning of the Old World Neolithic” (Marcos 2003, 7). Later, Ford (1969) established a looser definition acknowledging the diversity and multiple processes within the American continent: “Sedentism, agriculture, polished stone tools and ceramics did not occur simultaneously as expected” (Ford 1969, 5); neither were early sedentary villages correlated with a demographic explosion nor pottery exclusively developed by agriculturalists. Hence he defined the Formative period as “the 3,000 years (or less

in some regions), during which the elements of ceramics, ground stone tools, handmade figurines, and manioc and maize agriculture were being diffused and welded into the socioeconomic life (of peoples from Peru to the north-eastern United States), and that at the onset of these changes all these people had an Archaic economy and technology; and at its end they possessed the essential elements for achieving civilisation” (Ford 1969, 5). This diversity within the Formative period has been recognised by several scholars (e.g. Delfino *et al.* 2009; Lavallée 2006; Lederberger-Crespo 2000; Lumbreras 2006; Marcos 2003; Núñez *et al.* 2009; Staller 2006a; Terrell *et al.* 2003), recalling that Formative constituents and the potential causes and stages that lead to food production should be discussed in the context of the historical, social and/or environmental variables that affect each society. Lavallée (2006) summarises the current understanding of regional variations across the Andean Formative by commenting that the Central Andean Area represents the first area of South America where human groups became sedentary before the adoption (or invention) of agriculture, establishing permanent settlements on the Peruvian coast by 6000BP, which were dependent on the exploitation of marine resources. On the other hand, the oldest indices of manipulated vegetal species have been discovered in inter-Andean basins, in a context of hunting-gathering and semi-nomadism. As for animal domestication, various centres seem to have existed in Peru and Chile. Ceramics only appear at the end of the period (4000BP), with the technology originating in the North (Colombia and Ecuador) or from the eastern Tropical Forest (Lavallée 2006, 35).

For the Puna de Atacama, Olivera (2001) conceives the Formative stage as an adaptive system organised around distinct approaches to production, which can either use agriculture or pastoralism as a complement to continuities and developments in hunting and/or gathering. Over time, this leads to increasing levels of sedentism and the incorporation of new technologies, among them pottery. These societies may have had a limited degree of social differentiation and/or hierarchisation, and even if these productive strategies allowed a higher level of

sedentism, in the Andean zone a significant level of mobility was maintained in order to exploit different environments.

In this area, most researchers agree that domestication of camelids and herding precedes agriculture, and that this latter will come only later to complement herding practices, varying in its intensity and presence according to the cultural and natural scenarios of the Puna (Agüero 2005; Agüero *et al.* 2009; Benavente 1988-1989; Mengoni & Yacobaccio 2006; Muscio 2001; Núñez *et al.* 2009; Olivera 1998; Olivera *et al.* 2006; Yacobaccio 2006). “During the Late Archaic or Puripica-Tulan phase (ca.3000-1800BC), domestic camelids facilitated a new way of life that brought complexity and adaptive improvements, creating the necessary conditions for the neolithisation in the South Central Andes” (Núñez & Santoro 2011, 495). But whilst domestication of camelids and the onset of herding has been tracked with different data, such as morphological, osteometrical, lanimetrical, pathological and age profile analyses and other indirect evidence such as corrals and rock art (Cartajena *et al.* 2007; Hesse 1982b; Jackson & Benavente 2010; Muscio 1999; Núñez 1986-1987; Núñez *et al.* 1999; Olivera 1998; Olivera *et al.* 2004); arguments for the onset of agriculture have been based mainly on assumptions about the economical implications of occasional scarce crops macroremains and changes in technology and settlement patterns.

Agriculture in the western slope of the Puna de Atacama

In the southern edge of the Salar de Atacama subarea (see Figure 4 and 7), the Formative is known as Tilocalar or Early Formative (ca.1400-400BC) and Late Formative (400BC-500AD) (Núñez 2005). Whilst in the northern edge it has been divided in the Early Formative (1300BC–350AD) and the Middle and Late Formative, respectively represented by the Toconao (400BC-100AD) and the Séquitor phase (100-500AD) (Agüero 2005; Berenguer *et al.* 1986; Llagostera & Costa 1999; Núñez 1994; Núñez *et al.* 2006; Tarragó 1989). In the Loa subarea, these phases have their equivalence in Vega Alta (900-100BC) and the Loa Complex (100BC-400AD) (Aldunate *et al.* 1986; Benavente 1982; Pollard 1970; Sinclair 2004).

The Early Formative is characterised by the incorporation of new technologies such as pottery, with a strong degree of continuity from Late Archaic complex hunter-gatherers and herders, with semi-permanent settlements situated mainly in the ravines that border the oases of the Salar de Atacama and the ravines and meadows of the Middle Loa River (Agüero 2005; Benavente 1982; 1988-1989; Núñez *et al.* 2006; Núñez *et al.* 2009; Pollard 1971; Pollard & Drew 1975). The distinction between ravines and oases is an important consideration in these developments. Ravines are at higher altitudes (2500-3500masl) and have rich grasses and shrubs, suitable for the grazing of camelids, as well as an abundance of other small and large animals; whereas oases are mainly found in lower belts (2000-2500masl) and are characterised by the presence of forests of legume trees (*Prosopis* and *Geoffroea decorticans*).

During the Middle and Late Formative, sites in the ravines decrease their occupation and the oases of the Salar de Atacama start to be occupied with permanent settlements and cemeteries (Agüero 2005; Llagostera *et al.* 1984; Llagostera & Costa 1999; Tarragó 1989), whilst in the Loa River, settlements are expanded within previously occupied oases and meadows (Pollard 1970; 1971).

Within these changes, explanations about the onset of agriculture were supported by the influence of the traditional definition of the Formative period (Willey and Phillips 1958), the findings of scarce *Zea mays* cobs and *Lagenaria* rinds as well as the appearance of lithic hoes, together with the gradual occupation of the oases and abandonment of the ravines (Benavente 1982; Llagostera *et al.* 1984; Llagostera & Costa 1999; Núñez 1994; Pollard 1971; Sinclair 2004; Tarragó 1989). Sedentary villages on the oases, like Tulo 1 (400BC-100AD), and evidence of social complexity within the Toconao Oriente cemetery could only be achieved with an agro-pastoralist base (Barón 1986; Le Paige 1963; Llagostera *et al.* 1984; Llagostera & Costa 1999; Tarragó 1989).

Later Agüero (2005) looked for the origins of this “consolidated agriculture” in the northern area of the Salar de Atacama (Vilama/San Pedro oases), concluding that

the movement to the oases was a gradual process starting in the Late Archaic, which depended on the use of forest resources (*Prosopis* and *Geoffroea decorticans*) in association with animal resources in the ravines. Agüero argues that the incorporation of maize horticulture was developed by the Middle Formative (400BC-100AD) in response to social demands (Agüero & Uribe 2011), and the primacy of the oases over the ravines was established by the Late Formative (100-500AD) when the consolidation of Atacameños identity nurtured an intense interchange with trans-Andean populations (Agüero & Uribe 2011; Agüero *et al.* 2009). Within this model, Vidal (2007) proposes the adoption of agriculture as an evolutionary process (Harris 1989) which was intensified by the end of the Formative period. These authors and others (e.g. Adán & Urbina 2007) suggest that the populations of the oases and ravines during the Late Formative may have had distinct cultural traditions: one in the oases dependent on gathering and horticulture and another in the ravines where a population continued Archaic traditions of subsistence based on hunting and llama herding. Previously, migration of horticultural populations from outside the Atacama region was proposed for the oases sites, which exhibit the innovations of the Middle and Late Formative period (Barón 1986; Benavente 1988-1989; Tarragó 1989).

Alternatively, Núñez (2005) proposed that after the Early Formative (1400-400BC), the herding societies of the ravines moved to the oases looking for more land and better conditions to support an increasing human population and the ongoing complexity. For Núñez (2005), more permanent settlements in the oases are linked to agricultural activities and socio-political power is conceived as being situated within agrarian communities, which then expand again into marginal areas such as the ravines, to pasture their animal herds. These agro-pastoralist communities are thought to place greater emphasis on handcrafts and llama caravan exchange as they develop the complexity seen by the Late Formative and the eve of the Middle period (600AD).

In the Middle Loa, since the Early Formative, scholars have proposed mainly a herding and hunting-gathering economy with increased levels of sedentism

(Benavente 1982; 1988-1989; Pollard 1970; 1971), though the onset of a well-developed maize agriculture was achieved during the Loa II phase (ca. 100-300AD) when sedentary life was established (Pollard 1971).

Hence these models agree that farming (in the sense of a reliance on production of domesticated resources) started with the domestication of camelids in the Late Archaic; and that later changes, such as the movement to the oases and the appearance of larger and more sedentary settlements, were related to plant production with more or less emphasis on forest resources or agriculture and horticulture of maize. In the Salar de Atacama, Llagostera *et al.* (1984) propose maize production in association with llama herds at the site of Tulo, whilst Agüero and colleagues (e.g. Agüero & Uribe 2011; Agüero *et al.* 2009) and Vidal (2007) give more emphasis to gathering of the forests and horticulture, and Núñez (2005) proposes a consolidated agriculture by the Middle and Late Formative. In the Middle Loa, Benavente (1982; 1988-1989) and Pollard (1971) also support the argument of a llama herding during the Early Formative and the development of maize based agriculture by the Late Formative.

However, these diverse perspectives regarding the role that wild and domestic plant production had in the Formative economies are problematic:

On one hand most of them assume some food stress explanation for the onset of agriculture. However, environmental variables, increasing sedentism, social complexity and/or demographic pressures as previously suggested in the area (Agüero 2005; Agüero & Uribe 2011; Agüero *et al.* 2009; Núñez 2005; Pollard 1970; 1971; Tarragó 1989) should be tested more thoroughly if they are going to be used as explanations for the onset of agriculture and production of domesticates. Most of the Late Archaic and Early Formative sites are not dense occupations either in space or in stratigraphy and there is no clear evidence of strong hierarchization within local communities. Also environmental proxies are ambiguous, and even if some authors have proposed a link between more stable settlements in greener patches due to a rise in humidity by ca.1000BC (Grosjean *et al.* 2003; Grosjean *et al.*

1997; Grosjean *et al.* 2001; Núñez *et al.* 1995) and therefore the necessary conditions to start agricultural activities (Barón 1986; Llagostera *et al.* 1984; Núñez 2005), this environmental change should not be considered as sufficient cause for the onset of agriculture particularly without better proof that agricultural production does indeed increase. Moreover, if indeed food stress was affecting these Formative populations, this could have been managed by enhancing the productivity of wild resources, and by herding and hunting, and gained access to more distant resources through the growing llama caravan system for long and short distance exchange networks. In this sense, “food stress is not necessarily correlated with the onset of food production” (Price & Gebauer 1995, 4). Rather than making assumptions about external or internal causes triggering agriculture, I propose that a review of risk-spreading strategies provides a better approach that considers a range of factors and variables to explain why changes in subsistence and social organisation could have happened.

Also, current perspectives do not acknowledge the vast middle ground between food procurers and agriculturalists. They are based on limited evidence for the range and intensity of plant use. I agree with Vidal (2007) that evolutionary models (Ford 1985; Harris 1989; 1996a; Smith 2001b; 2006) can provide a useful perspective to explore the Formative societies of the Atacama Puna, but that we require better data to evaluate the changing relationships that these societies had with plants and nature.

Therefore the main objectives of this thesis are:

To achieve a fuller understanding of subsistence and cultural changes during the Formative period by providing new evidence to evaluate the degree of plant procurement and/or production, processing and consumption and their changing patterns through time and space; as well as considering broader theoretical perspectives to inform the interpretation of these changes.

To contribute to the debate regarding the Formative period and the understanding of the origins and spread of agriculture within the Andes and South America, where

primary data is still limited and hence the explanations for how, why, where and when agriculture was developed, adopted and consolidated are not consistent.

To make a methodological contribution by setting up the first microfossil reference collection for the area, as well as exploring the potential of analysing plant microfossils to complement macro-remains and re-evaluate the cultural hypothesis.

These objectives have been selected to answer the following questions:

Research questions

1. What plants were dominant and how were they managed by the Formative peoples living in the Atacama Region? Why and how do these patterns vary through time and space?
2. Why do lithic hoes appear during the Early Formative? Are they related to farming practices?
3. Why were new grinding technologies adopted during the Formative period? Are they related to the processing of new resources (crops)?
4. Why were previous occupations in the ravines abandoned and new permanent settlements in the oases established during the Formative period? Is this related to the onset of agriculture?
5. Is it possible to identify whether these changes are autochthonous or whether they relate to new populations moving into the area?

Structure and brief outline of the thesis

This dissertation is organised in ten chapters, the **first chapter** being this Introduction.

The **second chapter** presents a brief summary of different proposals regarding why hunter-gatherers shift to farming and how this transition has been interpreted for different cases through the Americas. Cultural historical, processual and post-

processual approaches are succinctly reviewed and exemplified, with particular emphasis on those approaches used in my discussion of data presented in this thesis. After this general review, I recall the models previously proposed for the Atacama to present an alternative perspective on the changes of this period based on a consideration of risk-spreading strategies and evolutionary models regarding human-plant interaction. In the Andes, risk-spreading strategies are widely recorded (Browman 1987b), and it is highly likely that these played a role in changing subsistence during the Formative. Regarding the role of plants and their management, this can be visualised and explored using some evolutionary models (Ford 1985; Harris 1989; 1996a; Smith 2001b). These approaches will enrich the discussion given in the area regarding the path from complex hunter-gatherers to farmers.

In the **third** chapter, I provide an environmental and cultural contextualisation of the area and periods of research. Geographically, I study sites located in the precordillera of the Atacama Desert (23 lat S) (2000-4000masl) in two main sub-areas: the Middle Loa and Salar de Atacama, which in turn comprise two ecosystems in which the sites studied are settled: mainly the oases and river/ravines with differentiated resources, although meadow is a third ecosystem used, which does not depend on altitude and can be present in the salar, adjacent to oases or at higher altitudes. These ecological differences have led to different forms of occupation and use of space and hence can be related to different subsistence strategies. Paleoenvironmental analyses are not conclusive and there are significant disagreements about how to interpret humidity trends through time. The cultural periods under study, namely the Late Archaic (ca.3000-1800BC), Early (ca.1400-400BC), Middle (ca.400BC-100AD) and Late Formative (alternatively ca.400BC-500AD or ca.100AD-500AD), are briefly characterised according to their main sites, subsistence strategies and cultural diagnostics (as this informs the selection of case study material in chapter six).

The **fourth chapter** presents a chronology for the domestication of a variety of crops recorded throughout the Americas in order to provide an overview of what

can be expected as potential crops in the Atacama area. In this summary, I have tried to consider the more recent and accurate data regarding domesticated specimens, acknowledging the problems and disagreements in their identification and cultural implications. **Appendix 1** provides a table with the chronology and locations of these earlier agricultural findings in South America, which maintains original data (as shown in the paper) but includes a normalisation of the data in years BP.

In the **fifth chapter** I provide a complete background specifically related to the data collected, analysed and interpreted for this thesis. A range of approaches (archaeological, ethnographic, ethnohistoric) regarding different sorts of evidence (wild and domesticated plants; animals; technologies related to plant manipulation and bioanthropological data such as kilocalorie models, osteological data, tooth wear and isotope analyses ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^{18}\text{O}$ and $^{87}\text{Sr}/^{86}\text{Sr}$) are described and evaluated in order to present what is currently known about foodways in the Atacama region against which I can compare and explain my data. I introduce the main artefacts and ecofacts I analyse in this thesis (wild and domestic plants, grinding tools and lithic hoes). This evidence is also discussed in relation to some relevant comparative data from other regions (e.g. Argentina, Middle East), which is useful to generate some expectations and explanations regarding my own samples for Atacama

The **sixth chapter** presents in detail the sites from which I took the samples, explaining their location, chronology, spatial organisation and the activities represented by cultural materials such as the sampled artefacts.

The **seventh chapter** presents my methodology. I collected and analysed micro-fossils attached to lithic hoes, *manos* and mortars, and analysed the proportion of isotopes ($\delta^{13}\text{C}_{\text{col}}$, $\delta^{13}\text{C}_{\text{ap}}$, $\delta^{15}\text{N}$, $\delta^{18}\text{O}$, $^{87}\text{Sr}/^{86}\text{Sr}$) within samples that I took from human bones and some rodents. Neither technique has been widely used in the area but they offer a useful complement to the previous work on macroscopic (carbonised or desiccated) plant remains.

The samples come from nineteen sites that represent the Late Archaic and Formative periods in the western slope of the Puna de Atacama, four sites in the Middle Loa (Chorrillos, Chiu Chiu 200, Ranl 273, Kalina) and fifteen from the Salar de Atacama area (Ghatchi 2C, Calar, Puripica 1, Puripica 23, Puripica 31, Tulo 1, Toconao Oriente, Tulan 54, 55, 57, 58, 67, 82, 85, 122). Most of the artefacts were available in museum collections and some do not have specific contextual information. Therefore, taphonomical aspects regarding the systemic and archaeological context and cultural and natural formation processes are discussed. Also methodological problems which directly affect the interpretation of isotopes (e.g. fractionation models) are discussed. Various appendices resume and summarise the data. **Appendix 2** presents the contexts and taphonomic variables that might have affected the artefacts sampled for microfossils. **Appendix 3** shows the complete images and characterisation of the microfossils of the reference collection. **Appendix 4** presents tables recording variants that characterise the starch grains for each of the species examined in the reference collection. **Appendix 5** shows an experiment to evaluate contamination by gloves with corn starch.

Chapter eight presents firstly the results of the archaeobotanical analysis. This first part describes and provides a systematic database of the archaeological microfossils found in the area. Hence identification problems and characterisations are described in detail alongside some diagnostic pictures of the microfossils found. After identifying these archaeological microfossils (based primarily on the local reference collection), I distinguish the microfossils as cultural or non-cultural based on taphonomic variables, archaeobotanical data and ethnobotanical knowledge. Finally, the cultural microfossils are organised and described regarding their attachment to tools and their presence/absence in sites and through periods. **Appendix 6** presents the complete database of the archaeological microfossils in Excel tables. The second part of my results chapter refers to the analyses of isotopes. Due to the small size of the sample, the values obtained are interpreted as major trends rather than site-by-site analyses. Here alternative interpretations are

shown regarding fractionation models. **Appendix 7** presents the complete databases of isotope samples in spreadsheets.

The **ninth chapter** presents my discussion. Here my research questions are answered based on my theoretical approach. Patterns of plant remains are presented and analysed in relation to an increasing level of human-plant interaction, showing a wide spectrum of plant types and levels of management. A strong reliance on wild plants argues against previous models which assumed that maize agriculture and/or horticulture was an imperative in Formative changes, and thus, I explain this within a broader Andean context of risk-management. A new model for the Atacama Formative is proposed based on the role that wild plants and domestic camelids have during this period and this becomes a new case to compare with Formative societies in other parts of the Americas, as well as with the broader transition from foragers to farmers. As most of the sites discussed are from the Salar de Atacama basin, the core of the discussion is built on them and to a lesser extent on the Middle Loa area¹.

Finally, some gaps in the current research are identified and potential improvements to the methodology and sampling techniques are discussed in relation to the prospect for future work in the area.

The **tenth chapter** present my conclusions, where I highlight the major points of this thesis as well as the contributions both to research methods and to an improved understanding of cultural changes in the Atacama, discussing how this work could be built upon and developed through future research.

¹ I did not have access to Rio Salado collections and therefore this area is not discussed in detail within this research.

CHAPTER II. THEORETICAL APPROACH

Introduction

In this chapter I review the main models and theoretical perspectives that have been used to explain why and how plant production was adopted by past societies. This review, although general, provides a clearer perspective from which to propose the theoretical framework assumed for this research and for re-interpreting the results and the current background of Atacama.

II.1 A comparative review of the onset of agriculture

Farming can be defined as a way of obtaining food that involves cultivating plants and herding animals (Price & Gebauer 1995, 3). This new productive form implied a long-term revolution with changes in the use of soil and in the organisation of human society (Price & Gebauer 1995, 6). The path from hunter-gatherer economies to farmers has been theorised especially for the Near East, where the recovery and analyses of a rich quantity and quality of data has allowed researchers to build several explanations for the origins of agriculture. (These explanations, developed for the Near East and Europe, have frequently been extrapolated and applied to other areas of the world where there is less data available). Accounts about how agriculture was then adopted by neighbouring social groups and established more widely have either emphasised the migration of farming populations or the diffusion of the knowledge of farming along with the exchange of crop seeds (Ammerman & Cavalli-Sforza 1973; 1984; Bar-Yosef & Meadow 1995; Bellwood & Renfrew 2002; Childe 1951); or evolution with or without intentionality (Harris 1989; 1996a; Rindos 1984). Attempts to explain the adoption of agriculture have identified a range of potential causes, including climatic change (Childe 1951; Wright, H.E. 1993); demographic stress (Cohen 1977); the combination of both (Binford 1968; Flannery 1969) as well as the inclusion of social imperatives and endogenous causes (Bar-Yosef & Belfer-Cohen 1989; Bender 1978; Hayden 1990; 1995).

In the Americas, the first reports that mention the presence of crops focused on tracking their “origins” and their diffusion from the core areas. Although some authors emphasised the role of independent domestication (Pickersgill 1971), the most common assumption was that each crop had a single place of origin and that the later spread and adoption of that crop was best explained by cultural diffusion and/or migration (Ford 1969; Heiser 1965; Lathrap 1970; Meggers 1985; Vavilov 1992 [1940]). The adoption of agriculture was seen as a natural outcome in the evolution of human societies which transited from hunter/gatherers to farmers. In this sense, it was assumed that agriculture was essential for the development of sedentary villages and complexity, it was thus considered an essential driver for the consolidation of the Formative period (Willey & Phillips 1958). Therefore, crops, together with pottery, architecture, economic intensification, household and community reorganisation with wealth accumulation and status differentiation at diverse levels, were assumed to occur together; and the presence of one or more key components were taken as indicators of the Formative stage of development in the American sequence (e.g. Kroeber 1930; Lanning 1967; Lumbreras 1974; Lynch 1967; Núñez 1974; Spinden 1917; Willey & Sabloff 1980; Willey & Phillips 1958). Here the presence of maize was assumed as an indicator of Formative life (Staller 2006a) and was seen as a homologue for the wheat and barley of the Old World (Staller 2006b).

The arrival of processualist theories changed the focus from dominant themes of chronology and typology to questions about subsistence models and the causes of changes. In some cases, researchers challenged the assumption that agriculture was a primary factor in the emergence of civilisations (Lanning 1967; Moseley 1975; 1992); however, most characteristic models explain the onset of food production as a necessity for maintaining larger populations with specialisation and social hierarchies that was triggered by external or internal variables. A representative example of the former is the “marginality theory” in which the shift to food production is seen as an adaptive response to either a reduction in the carrying capacity of the local environment and/or an increase in the size of the human population (Binford 1968). Population pressure and climate change are identified as major causes that could explain the origins of farming. An imbalance between available resources and human demands triggers behaviours that allow intensification and guide the process of

food production. This intensification could have involved small-scale activities (e.g. weeding, pruning and planting) and possibly some large-scale activities (e.g. irrigation or terracing) that led to domestication of species, population growth and greater production or productivity. Intensification as a reaction to social or environmental pressures also predominates in explanations about the origins of food production in the Andes (e.g. Babot 2004; Bruno 2008; Mengoni 2008; Mengoni & Yacobaccio 2006; Núñez & Santoro 2011; Rossen 1991).

The perspectives based on endogenous causes emphasise social competition (Bender 1978). Here human ambition includes a desire to control power and available wealth in complex hunter-gatherers, leading to the desire to amass a food surplus and prompting food production. Within this same conception, Hayden (1990) believes that non-egalitarian societies promoted specific forms of food production to facilitate feasting and a developing interest in status differentiation through prestige objects. In this mode, Bruno and Whitehead (2003) suggest that the start of agricultural production in the Titicaca basin was linked to developing socio-political complexity. Dillehay *et al.* (2011), studying data patterns from the north-western Peruvian Coast and inland areas, also put more emphasis on social decisions rather than on environmental causes. Emerging social inequality promoted the production and exchange of rare status and ritual items from the coast and the highlands. In this explanation for the development of increasing social complexity, “domesticated plants provided an excellent resource for status differentiation at the individual and household levels” (Dillehay *et al.* 2011, 272).

Another major approach to explain the origins of food production is the evolutionary perspective, which emphasises the idea of a gradient continuum, on which frontiers are not static or unilineal and different levels of management of wild and domesticated plants and animals can be found. In this sense, the development of agriculture should not be seen as a revolution but as a gradual process or a transition with different characteristics and timing of adoption through the Americas (Pearsall 2009; Pickersgill 2007; Smith 1998a; 1998b; 2001b; Staller 2006a; Terrell *et al.* 2003). This evolution can have a fluctuating movement, with both gathering and agricultural production playing more or less significant roles depending on different environmental and cultural variables, where both are part of the

same cultural rationality and can be interchanged and adopted episodically (Boado 1993, cited in Korstanje & Würschmidt 1999, 152). Scholars have attempted to classify different levels and relations of human-plant interaction between complete dependence on wild sources of food (hunter-gatherers) and predominant dependence on domesticated plants and animals (farmers) (e.g. Ford 1985; Harris 1969; 1989; 1996b; Higgs 1972; Jarman *et al.* 1982; Rindos 1984; Smith 2001b).

For instance, as a three-stage model of human/plant interrelation, Rindos (1984) embeds the concept of domestication within “co-evolution”, defining it as an unconscious symbiotic relationship between humans and plants. He defines three stages in the domestication process (Rindos 1984, 138-139). The first stage is incidental domestication, which refers to human dispersal and protection of wild plants in the general environment. The second is a specialised domestication caused by the human impact in the environment creating anthropogenic locales where plants and humans influence each other intensively, and the third is agricultural domestication, which is the culmination of the coevolutionary process and produces plants adapted to a special set of humanly created conditions: the agroecology. Pearsall (1989; 1995; 2008) has used this approach within the discussion of the domestication and onset of agriculture in different areas of South America. This process is the natural “outgrowth of forager-plant interactions, with no external push required” (Pearsall 2008, 119). She proposes three thresholds of domestication and agriculture in the Andes: 1. During the Early Holocene there were domesticated plants, some of them more advantageous than others, leaving a trace in the record; 2. Early domesticates and small-scale agriculture spread through social interaction among foragers/horticulturalists; 3. Increase in crop production fuelled population growth, which led to the spread of farming populations out of their areas. Within this approach, the co-evolution between plant/animal domestication in the Peruvian Highlands has been emphasised (Kuznar 1993; Pearsall 1989; 1995).

Ford (1985) proposes a categorisation to clarify the interactions between plants and people with different stages and methods of plant food production. The first stage is foraging and refers exclusively to distinguishing the utilisation of wild plants from any and all forms of human intervention in the life cycle of plants or food production; this latter and second

stage is divided into two sub-stages: cultivation and domestication of wild species or domesticates. He recognises three main methods of food production, namely incipient agriculture, gardening and field agriculture, and different types of interaction such as tending, tilling, sowing, transplanting and plant breeding. This sequence progressively succeeds, ultimately leading to full domestication of plants and agriculture (Figure 1).

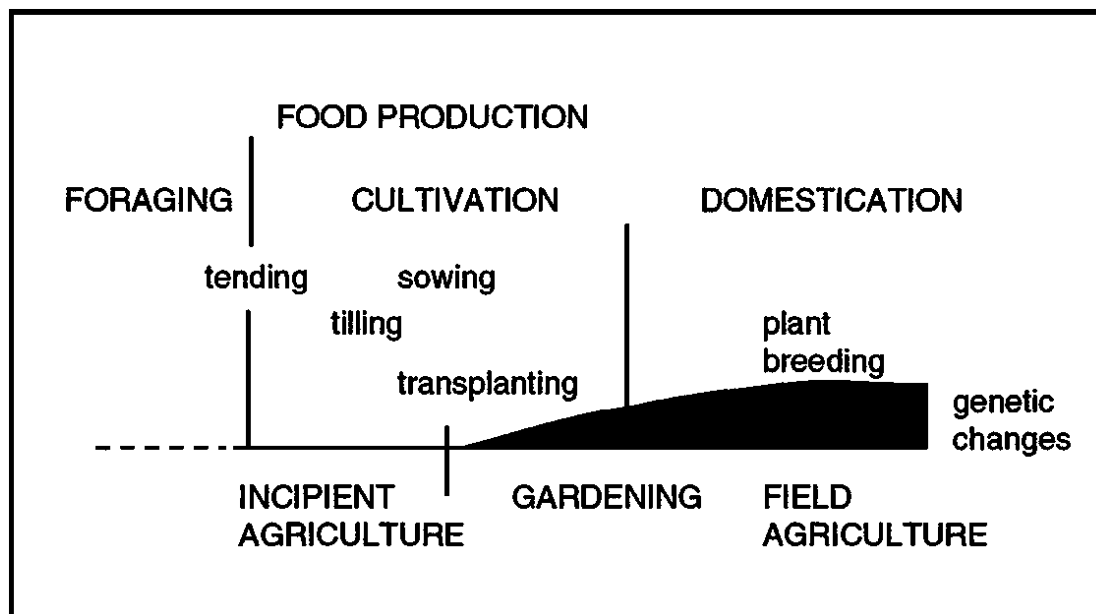


Figure 1. Stages and methods of plant food production. Reproduced from Ford (1985, 2).

Harris (1989; 1996a) projects a descriptive model named a continuum of people-plant interaction where a progressive gradient of increasing energy per unit area of exploited land leads from foraging to farming (Figure 2). As cited in Fuller (2007, 903); Harris (1989) distinguishes four general stages: (1) wild plant food procurement (true hunting and gathering), (2) wild plant food production (the very beginnings of cultivation), (3) systematic cultivation (of morphologically wild plants) and finally (4) agriculture based on domesticated plants. Each of these stages reflects an intensification of production that can result in higher levels of sedentism, population density and/or social complexity. However, this process is neither unidirectional nor deterministic and is composed of different activities and food yielding systems. For example cultivation in the absence of domestication is not unusual among Neotropical trees (Hughes *et al.* 2007, 14392); or societies like the Jomon in Japan or in the Amazonas never became fully agriculturalists in despite they knew and practice agriculture (Crawford 1992a;b; Gould 1985 cited in Smith 2001b).

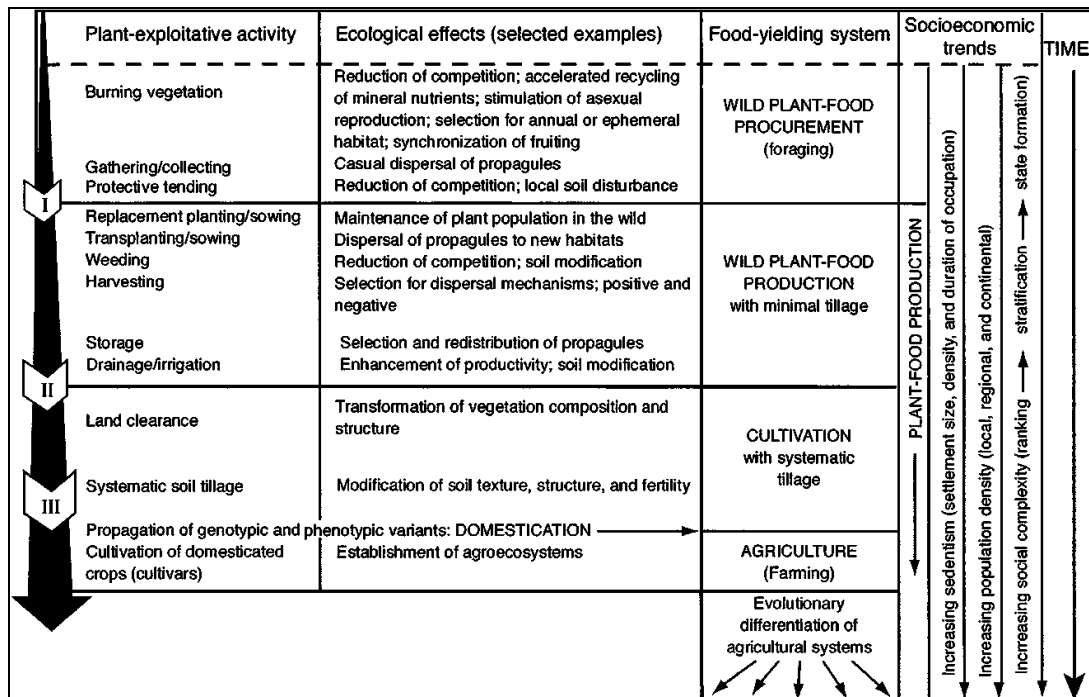


Figure 2. Classificatory and evolutionary model of plant-food yielding systems. Reproduced from Harris (1989, 17).

Later, in 2007, Harris defines a biotic resource specialisation concept which “encompasses the whole spectrum from wild food procurement (hunter, gathering, foraging); through the management of selected plants and animals to enhance their productivity in systems of wild food production until the genetic isolation and morphogenetic domestication of particular taxa” (Harris 2007, 29).

Smith (2001b) defines societies with “low level food production”, in the middle ground between hunting, fishing, foraging and agriculture. He defines low-level food producers with and without domesticates. The former are characterised because crops contribute less than 30-50% of the total annual calories, whilst the latter tended non-domesticated plants. Both modified the environment to enhance the productivity of selected species. “The societies of the middle ground are not pale reflections or logical extensions of either agriculturalists or hunter–gatherers, but a separate general class of extremely variable, successful long-term socioeconomic solutions, fine-tuned to a wide range of local cultural and environmental contexts” (Smith 2001b, 33-34). Hence the presence of domesticates does not define the boundary of either agriculture or hunting and gathering, but rather is situated well away

from both border zones (Figure 3) and provides an excellent vantage point from which to consider both of these poorly mapped regions on either side (Smith 2001b, 17).

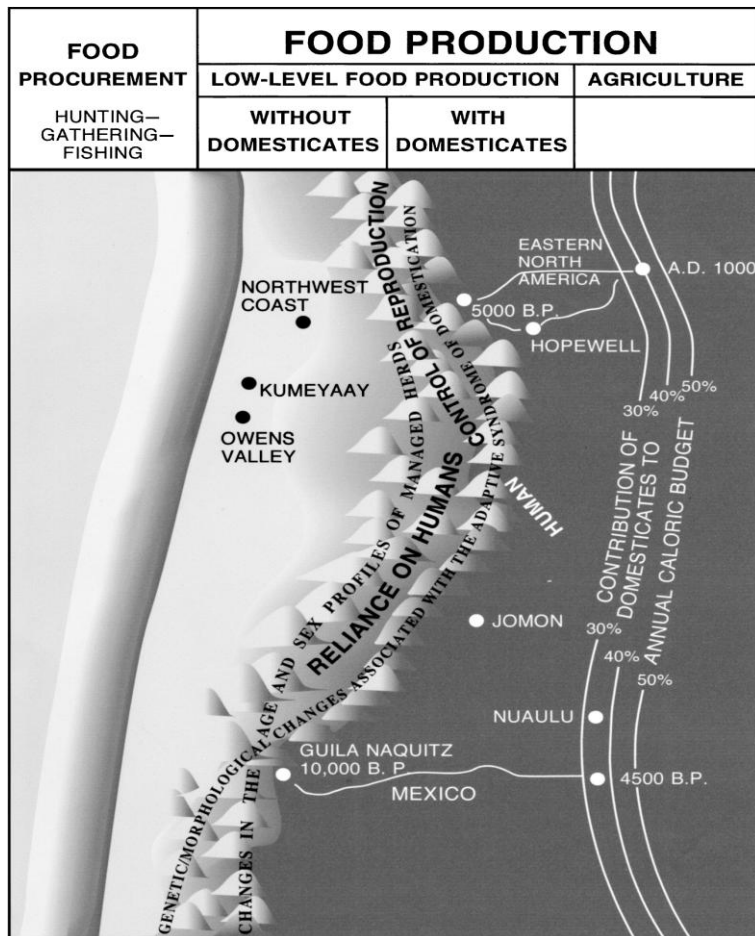


Figure 3. Conceptual development map of the middle ground between hunting-gathering and agriculture. Reproduced from Smith (2001b, 15).

However, the concept of domestication has different implications and definitions. For Smith (2001b; 2006), the central defining characteristics of domestication and the creation of domesticates is the nature of the ongoing relationship of intervention initiated and sustained by humans: “the behavioral relationship is domestication” (Smith 2006, 17). Zeder (2006) proposes three axes in this relationship between humans and target plants and/or animals. The first axis is the intentionality involved in this process, the second, the balance of power between domesticate and tamer, and the third the locus of change. Regarding these latter, morphological or genetic changes are not universally accepted as happening in all species. This especially applies to animals or perennial plants “such as root crops propagated through vegetative cloning or very long-lived tree crops in which genetic and morphological change may be less automatic and more subtle than in annual seed crops”

(Zeder 2006, 106). Coinciding with Smith (2006), she states that it is better not to obsess about the exact demarcation between domestic and wild, but rather to consider the “full span of the evolving nature of domestic relationships” (Zeder 2006, 106). For Harris (1989), domestication is a continuum of human investment in selection and environmental manipulation, so its subcategories are merely constructs that imperfectly reflect the real world (Clement 1999, 189). However, he holds to the orthodox definition, which necessarily involves morphogenetic change and its use as a defining criterion for agriculture, though the agricultural condition of a society depends on the relative importance of domesticated and wild plants and animals in the subsistence economy (Harris 1989, 21). Within Harris’s model (1989), Fuller (2007) discusses the different stages and timing of domestication for different plants and species. “The transition from the ancient wild forms to the modern domesticated forms was an evolutionary process, and it is necessary to ask whether this can be broken down into distinct stages relating to different selective pressures and human behaviours, and at what rate this evolutionary process took place” (Fuller 2007, 904). Wild food production preceding morphological domestication represents an important change in plants, which can be explored through the ‘domestication syndrome’, which highlights a set of characters that differ between domesticated crops and their wild ancestors, providing clues as to the selective pressures that make them evolve. Whilst Fuller (2007) describes the domestication syndrome in Old World seed species, Pickersgill (2007) describes it for the New World, exploring the molecular genetics of plant domestication. She states that crops “vary within and between species in their degrees of domestication and the fixation of domesticate traits. ‘Domesticated’ may therefore describe entire species or just some of the variants within species” (Pickersgill 2007, 925). Smith (2006) acknowledges that “morphological change falls at the tail end of what usefully can be characterised as a three-part process”, which can simplistically be summarised as behavioural change / genetic change/ morphological change. This scheme clarifies the three general categories of evidence for domestication that can be sought in the archaeological record (Smith 2006, 16). Hence, different markers (morphological and non-morphological) may be more effective in detecting different stages of this process which operate at different scales of both particular species but also in the whole landscape and social life. In this sense, besides domestication of particular species, landscape domestication has been used within

evolutionary models to track the origins of agriculture and processes that lead to it (e.g. Clement 1999; 2006; Harlan 1975; Rindos 1984; Terrell *et al.* 2003).

Domestication of the biotic and abiotic landscape is a cultural process, where human knowledge about the consequences of environmental manipulation accumulates and becomes more comprehensive over time (Harris 1989, cited in Clement 1999, 189). Clement (1999, 190-191) defines landscape domestication as a “conscious process by which human manipulation of the landscape results in changes in landscape ecology and in the demographics of its plant and animal populations, resulting in a landscape more productive and congenial for humans”. The intensity of manipulation may vary widely, from pristine to monoculture, with promoted, managed, cultivated and swidden fallow stages within this spectrum. Terrell *et al.* (2003) also assess that to “understand domestication, what must be taken into account is not only the story of particular species, but also the whole range of species—the species pool—from which transformed species have been drawn, for it is not just singular species but landscapes that human beings have been domesticating since the dawn of human time” (Terrell *et al.* 2003, 329).

As I will discuss later, several concepts and categories of these evolutionary models may be pertinent to explore the relationships between humans and plants in the Formative societies of the Atacama, and therefore need to be defined more accurately.

Recently Human Behavioural Ecology has gained wide acceptance in the explanation of the beginnings of food production in the Americas (Gremillion 1996a; Minnis 1992; Piperno & Pearsall 1998a; Winterhalder & Kennet 2006). This approach sees food production as an outcome of subsistence decisions made on the basis of relative return rates of exploitable resources in the environment (Piperno & Pearsall 1998a, 11). The triggering of the change from foraging through mixed economies to those that take up full-time agriculture considers the influence of environmental change or population pressure, but different models are applied based on optimal foraging theory. These tools make human behavioural ecology a “fertile source of archaeologically testable hypotheses about the subsistence and economic changes associated with the origins of agriculture” (Winterhalder & Kennet 2006, 9). This approach has been applied in studies of the Argentinian Puna (Muscio 2001) and the Peruvian Highlands, especially regarding camelid domestication (Aldenderfer 2006), in the

Lowland Tropics (Piperno 2006b; Piperno & Pearsall 1998a) and in the US borderlands (Minnis 1992). Aldenderfer (2006) uses two models employed in human behavioural ecology: diet breadth and costly signalling theory, aiming to define an optimal diet and capture the changes in labour, status, and the decision-making process of agents engaged in a transition from a foraging lifestyle to one based upon herding (Aldenderfer 2006, 169). He utilises the concept of risk and applies this to understand human decisions in the Andes, where he claims it is particularly useful due to the harsh environment and ecological pressures to which Andean people are subjected. Winterhalder and Kennet (2006, 18) propose that “foragers in positive energy balance will be risk averse”. “If agriculture becomes more profitable or less risky (given the same level of labour investment), or if foraging becomes less profitable or more risky, the household will increase its allocation of labour to agriculture” (Tucker 2006, 38). The adoption of a new crop can either occur in times of scarcity or abundance, depending on whether the goal is optimisation or risk avoidance (Gremillion 1996b). Following a risk goal, the introduction of new elements will be more likely to occur in areas and periods of resource abundance (Price & Gebauer 1995). In this transition, the new element is seen as a risk minimiser, allowing an initial diversification. Then, through a co-evolutionary or intensification process, it may subsequently become an efficient source of large scale food production (McClure *et al.* 2006).

Piperno (2006b) uses optimal foraging theory (OFT) to examine the origins of plant cultivation and domestication in the American tropics. She tries to identify important environmental and social variables that were acting as selection pressures on subsistence choices on the eve of the Formative period. In her review of the transition to food production in Panama, she rejects the idea of affluent foragers as a prerequisite. Considering ecological conditions of the Tropical Forests and the availability of resources, she claims that hunter-gatherers decided to produce food because it was a more reliable and less risky alternative in the tropical environment. Piperno and Pearsall (1998a) also make a useful contribution in our understanding of the onset of agriculture in the Lowland Neotropics. Within Human Behavioural Ecology, they use the “diet breadth model”, which allows predictions to be made about prey choice and dietary diversity, especially when

paleoecological data is robust and can serve as a useful proxy to understand the distribution and abundance of resources.

Also within a Human Behavioural Ecology approach, Minnis (1992) analyses the transition from hunting to farming in the desert borderlands of the US, which is environmental and ecologically very similar to the Western Atacama Puna Desert. Besides the common aridity and water fluctuation inherent to any desert, this environment shares with the Western Atacama Puna the presence of tree legumes (*Prosopis* sp.) and cactus. Also, like the Atacama, the desert borderlands of the US were not a centre of primary crop domestication: therefore, his analysis is useful as a comparative approach. Minnis defines two models to explain why inhabitants would decide to start cultivating: 1. Model of necessity and 2. Model of opportunity. The first one is related to food stress models, whilst the second poses the advantages offered by cultivation (greater control of the timing of food collection and increased yields). He suggests that inhabitants do not take the risk of leaving archaic hunter-gatherer patterns, so they retain their seasonal cycles and mobility, incorporating within this schedule the casual cultivation of crops with requirements that were similar to naturally available wild foods. Therefore, food collection, preparation and processing would not require substantial changes. In this sense, cultivation did not imply a disruption of the existing economic system and low intensity agriculture provided an excellent economic insurance when important foodstuffs were unavailable or available only in reduced amounts (Minnis 1992). It was only after 1000-3000 years that intensive agriculture was developed due to demographic pressure (Minnis 1985).

Finally, post-processual paradigms draw upon the work of symbolic and structuralist anthropologists (Douglas 1972; Leach 1964; Levi-Strauss 1966) to re-evaluate the status of food within the sphere of economic production and subsistence and consider the potential that food has for understanding cultural and social patterns. Hastorf (1999; 2006) has clearly shown how cultural preferences might have influenced the adoption of crops and farming practices. Following Farrington and Urry (1985), she states that the adoption of crops in the earlier times could have been stimulated more by cultural symbols and kinship rather than hunger or starvation. "Most scholars agree that early plant movements did not have a calorific or demographic cause" (Hastorf 1999; 2006). Developing this idea, Hastorf looks at

the onset of agriculture along the west coast of Peru over a long time span (8000-1400BC). Rather than political pressures (Bender 1978; Hayden 1990) to explain early cultivation, she favours small-scale family inter-relationship networks, through which wild and domesticated plants were transformed due to curiosity, experimentation or as identity markers. Women would have played a primary role in the tending and mothering of these plants in the new environment, nurturing them in their kitchen gardens and teaching new generations about them. The archaeobotanical data show a selective uptake by inhabitants in different valleys and are interpreted as part of identities and group formation in the beginning, changing toward political necessities in later times.

II.2 Perspectives for the western slope of the Puna de Atacama

In the light of this brief review of theoretical perspectives regarding why and how humans shifted from gathering to farming, and considering the current background and problems to understand this process in the western slope of the Puna de Atacama, I proceed to review particular spread risk strategies used in the Andes (Browman 1987b) as well evolutionary models for which the definition of key concepts and different categories of human-plant interaction will be provided to examine and discuss these middle ground societies.

-Risk strategies in the Andes

Due to the extremely harsh environment of the Western Atacama Puna and the Southern Andes (see Chapter III), risk management is considered relevant in any discussion (e.g. Aldenderfer 1998; 2006; Browman 1987a; 1987b; 1987c; Brush 1982; Custred 1977; Escola 1996; Goland 1993; Hesse 1982b; Kuznar 2001; McCorkle 1987; Olivera 1998; Winterhalder & Kennet 2006), being one of the principal economic organising strategies of arid land producers (Browman 1987a; 1987b). Several strategies to manage risk have been well recorded in historical, ethnohistoric, ethnographic and archaeological evidence from the Atacama area; therefore I assume that risk management might have played a role in the decisions taken by Late Archaic and Formative populations. However, risk-spreading strategies in this context are not seen just as a set of micro-economic goals, as Human Behavioural Ecology often understands them (Winterhalder & Kennett 2009), but are intimately linked with social and cultural values. Castro and Bahamondes state that to

understand how Andean indigenous people face climatic restrictions, “it should be considered in the analyses the existence of three cultural levels, closely interrelated: a) the technical, b) the social one, and c) the symbolic or ideological. The technical level refers to the system used to appropriate and to transform the nature (techniques, tools and infrastructure); the social plane is related to the organization they have for the production system. And, the symbolic level corresponds to the cosmogony where they find explanation about the world, the relationships between men, and their bond with supernatural forces” (Castro & Bahamondes 2001, 3).

Following Browman (1987b, 2), I review the main strategies used by Andean communities. Although these strategies are deeply intertwined, I will present them independently, giving some examples of each, primarily from the Puna de Atacama area (Table 1).

	<i>Risk-Spreading strategies</i>	<i>Andean models and examples of risk strategies</i>
A	<i>Development of social networks to share risk</i>	<i>Territorialidad salpicada (scattered territoriality)</i> <i>Movilidad giratoria (swivel mobility)</i> <i>Ayni</i>
B	<i>Specialised settlement patterns and spatial distribution to provide flexibility in avoiding risk</i>	<i>Archipiélagos verticales (vertical archipelagos)</i> <i>Complementariedad ecológica (ecological complementarity)</i> <i>Centro-periferia (central-periphery)</i> <i>Zonificación Andina (Andean zonation)</i> <i>Pueblo-estancia (town-village)</i> <i>Transhumancia (transhumance)</i>
C	<i>Diversification of productive activities to spread risk</i>	<i>Racionalidad Andina (Andean rationality)</i> <i>Household division</i> <i>Broad Spectrum economies</i>
D	<i>Development of special productive techniques to maximise both off-take and storability resources</i>	<i>Intensification</i> <i>Crop rotation, manure, fallow, weeding, new techniques and technologies</i>
E	<i>Enhancing carrying capacity to reduce productive risk</i>	<i>Storability</i>

Table 1. Risk-spreading strategies with some Andean examples (Browman 1987b, 2).

a) Development of social networks to share risk

Social networks in Atacama provided people with access to different products and ensured not just their biological survival but also their cultural and social reproduction. Overall, these social strategies confronted natural limitations and reduced risk because they extended the availability of products and resources in time and space. Hence local production was not the

only source of resources; in fact, the aim was not only for local consumption but also for exchange, so that the societies could access some goods from beyond their local ecology. Different models have been proposed to explain the nature and function of these systems, which become more diffuse as we move back in time. For instance, this strategy is at the core of Martínez's (1998) model. Based on ethnohistoric data from the Atacama Puna, he states that "Complementarity was overall human and then ecological" (Martínez 1998, 38). He sees that marriage and the creation of social relationships as *compadrazgo* by family units would have a clear intention to diversify and expand the spectrum of resources. In this way, reciprocity on the move and inter-ethnicity structured the complementarity. These kinds of relations would guarantee access to multiple resources directly or indirectly. To access or mediate the access to non-local resources, Atacameños would use the llama caravans and may have settled in distant territories, even for a lifetime, but conserving their social ties and identities with Atacama. This model would not mean an *archipiélago* nor an island (Murra 1975), but an interdigitation of peoples. In this sense, Atacameños coexisted with "foreign" groups, not just in the Atacama but also in the wider subarea known as Circumpuna. This area has common elements and singularities that distinguish it from other Andean groups and spaces (e.g. high Puna/Aymaras). The emphasis of this strategy is not focused on productive zones themselves but on the links that connect them. In fact, caravans are directed to regions where peoples have already pre-established relations (Aranda 1961-64). Interchange implies a complex and extended system of social relations at an intercommunity and interethnic level, which have been arranged over a long time and which involved prestige and socio-political management.

Another model that emphasises networks as a risk-spreading strategy in Atacama is *Movilidad giratoria* (Núñez & Dillehay 1979). In relation to the extraordinary ecological diversification of the Andes, these authors propose that independent herding/caravanning groups would carry goods and ideologies by circuits that connected at least two nodes settled in different ecozones (puna, coast, yungas). Also, there was a local traffic that connected the poles with smaller sites in the Atacama (Núñez & Dillehay 1979; Sepúlveda *et al.* 2005) and therefore one should consider different levels of trade and the variability

inherent in it (Torres-Rouff *et al.* 2012). This model could have started as early as 8000BC within a hunter-gatherer context (Berenguer & Dauelsberg 1989, 145).

In the Andes, critical and limited periods of production can require a great amount of labour input, which is incompatible with the low number of individuals per household (Brown 1987, 106). Therefore, by creating alliances, greater amounts of labour are available to each family and the work can be done on time. This reciprocal cooperation through labour exchange is known as *Ayni* and is one of the most basic and traditional institutions in the Andes. Another approach that refers to labour organisation is "*Racionalidad andina*" (Golte 2001). Golte focuses on explaining the rationality behind the organisation of the Andean communities. In this sense, he rejects the "Andean ideal" shared by distant ethnic groups to have access to different resources (Murra 1975), seeing it more as an "Andean necessity" in order to cope with the harsh and limiting environment of the highlands (low technology, no traction animals, extreme temperatures, poor soil).

b) Specialised settlement patterns and spatial distribution to provide flexibility in avoiding risk

This is among the most widely reported strategies in the Andes and has been explained under different models. The most paradigmatic model is that of ecological complementarity (Murra 1972; 1975; 1985a; 1985b). Murra (1972) suggests an Andean ideal of simultaneous access to a maximum range of ecological environments, by the settlement by colonies from natal communities on the highlands in diverse ecological niches (*Archipiélago vertical*). He states that Andean peoples, embedded within their knowledge of this highly diverse landscape and resources, managed to bring them together within a single economic macro-system. Murra's model has become one of the defining characteristics of Central Andean societies. Considering the data of Atacama, Hidalgo (1985) shows remnants of the vertical archipelagos during the XVI to XVIII centuries. Also in the Intermediate period on the Salado River, Castro *et al.* (1984) describe an altiplanic migration known as the Toconce Mallku Complex settled with a "very altiplanic idea of the ecological complementary" (Castro *et al.* 1984, 18). So far, no earlier archipelagos have been documented in the area.

Murra (1985b) was explicit on the limits of his model and Lumbreras (1973, cited in Hidalgo 1985) has been critical about its overuse to the exclusion of other Andean mechanisms for direct access to resources like transhumance or scattered settlements. Brush (1976) defines three patterns of Andean zonation and how they are used by the population. The first one is the compressed type, which refers to the compactness of the resources within a single valley, such that the organisation of their exploitation does not require movements or trade networks to acquire subsistence resources. The second is the archipelago type, which involves wide separation between exploited zones and hence migrations from the community and exchange or redistribution of resources by the centre. The third is the extended type where zones are contiguous and continuously exploited and hence generate an even spread through the valley (Brush 1976, 161-163).

On Atacama, since pre-agricultural times and afterwards, a transhumant movement is emphasised within the different altitudinal belts in order to acquire the diverse resources seasonally (Druss 1976; Le Paige 1975; Núñez 1980; 1981a; 1981b; Núñez & Santoro 1988). Atacama communities are characterised as having a scattered and complementary settlement pattern, which alternates residences in permanent villages and temporary residences known as *estancias* or *chacras* (Villagrán *et al.* 1998a). Romo (1998) describes how herders can possess permanent and temporal residences. All of the families have one or two houses, which are the main residential sites throughout the year, although if the herders move through longer periods they have various smaller residences scattered through a wide territory (Romo 1998, 220). Hidalgo (1985) mentions the double residence in a pattern that combines agriculture with livestock and transhumance, the *minifundismo* or dispersal of property (e.g. Peine-Tilomonte) and migratory movements or traffic of groups that looked for complementarity through barter (Hidalgo 1985, 163). Martínez (1998) describes that this settlement pattern would comprise a main unit (generally an agricultural settlement in the oases) with a centralising role of other minor units (more transitory on the puna) and would have contained different ethnicities. This pattern of central-periphery units was reinforced during colonial times by the effort to centralise communities on the lowlands or oases; and today it is represented by the pueblo-estancia on those communities that still practice herding (Sanhueza 2008). It is not certain to what extent this structure derives from

pre-Columbian organization, though it seems that dispersion within the Atacama and further territories was a common practice before the Spaniards arrived in the area (Hidalgo 1984; Martínez 1998).

c) Diversification of productive activities to spread risk

At this point I will briefly discuss organisation of labour within households. Also some economic strategies that allow diversification will be discussed, although they can also be aspects of issues raised under point d (below).

Within households, division of labour on the basis of gender and age helps to manage different activities simultaneously. "The pragmatics of how Andean households organise their economic activities can be better explained by considering their perception of risk and attempts of risk spreading" (Sillar 2000b, 46). In Atacama, Bowman (1942, cited in Hidalgo 2004, 91) shows that during ethnographic times, children and elderly people stay in the oases to take care of their properties and limited harvests whilst herders lead the herds to upper lands.

Another example of diversification is the achievement of security by having broad spectrum economies which combined herding, hunting, gathering and agricultural activities in different proportions through time and space. This variability is crucial, and was vital in the subsistence of Andean populations (Olivera 1998, 170). Diversification is present at every level of Andean economies. Households will usually be involved in a wide range of economic activities and social relations, working as a small-scale co-operative that makes them highly resilient to adverse circumstances (Sillar 2000b, 46). Also farmers will avoid specialisation or mono-cultivation, preferring diversity of crops and varieties within them, in order to secure that at least one type of crop will survive potential hazards (Tapia 2000). Herders also employ a number of risk-sharing techniques, such as moving herds seasonally to take advantage of locally occurring conditions, herd dispersion over wide areas to take advantage of local patch types, multi-species diversification or herd size increase (Browman 1987c, 123).

d) Development of special productive techniques to maximise both off-take and storability resources, which here I relate with e) Enhancing carrying capacity to reduce productive risk, as both strategies are related to productive techniques.

Whether their implementation is focused on maximising resources or reducing risk will depend on each context.

Some of the productive techniques that allow maximising off-take as well as enhancing carrying capacity can be seen under the concept of intensification. Several authors have seen that intensification is not necessarily related to social complexity or demographic pressure, but to risk strategies (Colson 1979; Halstead 1989; Nichols 1987). Among these strategies are plot and crop rotation and sectoral fallowing as well as dung collection (Guillet 1987). Other ways of intensification include activities such as pruning or weeding (Bruno 2008). Also innovation or the adoption of new technologies such as hoes and ploughs or the shift in the morphology of grinding tools could help to intensify production or productivity (Bruno 2008; Wright 1994). The resulting increased production of processing could produce a surplus that could reduce the risk of “off seasons” through storability. Different technologies and techniques looking for better preservation and storage of food are essential in Andean economies (see Chapter V, V.2).

-Concepts and terms use in this thesis derived from Evolutionary theories

I have already mentioned above the key components and scholars that represent this approach (Ford 1985; Harris 1989; 1996a; Rindos 1984; Smith 2001b; 2006), thus here I will define those concepts which might contribute to broadening the perspective with which to address the Formative human-plant interaction in Atacama. “There is little agreement about what precisely is meant by such terms as agriculture, horticulture, cultivation, domestication and husbandry. This semantic confusion militates against clear thinking about the phenomena we investigate” (Harris 1996a, 3).

In Atacama, horticulture and agriculture concepts are continuously used, referring to the reliance on crops and cultigens (Agüero 2005; McRostie 2007; Núñez 2005; Sinclair 2004; Vidal 2007). Gathering is used regarding wild food collection and Vidal (2007) proposes an

increasing use of *Prosopis* forests by the labels of intensive gathering followed by a period of specialised gathering (Vidal 2007, 133).

Within evolutionary models, crops are defined as plants that “do not exist naturally in nature; they cannot normally survive without human assistance” (Ford 1985, 6) or “that genetic and/or phenotypic selection has led to morphological change and a degree of dependence on human actions for the plant’s survival” (Harris 1996, 446).

Cultigens refer to plants that do not exhibit any morphological markers of domestication yet, but because of their abundant representation in archaeobotanical assemblages, are suspected to have been generally encouraged by humans in a manner that carries them beyond the realm of simple harvesting of wild plants (Smith 2001b, 20). More intermediate categories between wild plants and crops are given by Clement (1999). He recognises different stages in domestication according to human intentionality: 1. Wild: plants that not been modified by human intervention. 2. Incidentally co-evolved: A population that volunteers and adapts in a human disturbed environment, possibly undergoing genetic change, but without human selection. 3. Incipiently domesticated: A population that has been modified by human selection and intervention (at the very least being promoted). 4. Semi-domesticated: A population that is significantly modified by human selection and intervention (at the very least being managed) so that the average phenotype may diverge from the range of variation found in the wild population for the trait(s) subject to selection. 5. Domesticated: A plant population similar to (4) but whose ecological adaptability has been reduced to the point that it can only survive in human-created environments, specifically in cultivated landscapes. 5.1. Landrace: A domesticated (or occasionally semi-domesticated) population selected in a cultivated landscape within a restricted geographical region with high phenotypic variability and relatively high genetic variability, and 5.2. Modern cultivar: A highly selected and modified plant population or clone adapted exclusively to intensive monocultures with much reduced phenotypic and genetic variability (Clement 1999, 190).

Gathering is defined within a food procurement stage (Ford 1985; Harris 1989; Smith 2001b), which basically defines pre-Holocene hunter-gatherers. From here until agriculturalists, a middle ground or low-level food production with or without domesticates

(Smith 2001b) or a food production level that can imply the cultivation of wild and domestic plants is defined (Ford 1985; Harris 1989; 1996a).

Hence, another important term is 'cultivation', from the Latin verb *colo*: to till the land, though it commonly refers to tilling the land for crop production. However, as with other verbs and activities such as clearance, weeding, sowing or irrigation, 'cultivation' is used not just for domesticated plants but also for wild plants (Ford 1985; Harris 1989; 1996a) and hence become a useful term to explore the middle ground (Smith 2001b). Ford (1985, 4-5) defines tending as the encouragement of plant growth both by direct care of target species and by limiting competition, primarily through weeding. Tilling is deliberate soil disturbance with a digging stick or hoe to facilitate and encourage the appearance or germination of target species. Tillage could involve deliberate efforts to expand the size of stands of seed plants through soil disturbance around such stands in advance of natural seed dispersal, or the churning of soil and detachment of bulblets and lateral tubers during the harvesting of roots and bulb-bearing species. Transplanting is defined as the movement of a plant, usually perennial herbs and shrubs, or a tree from one locality to replant in another for easier access. It can be quite casual and scattered, or can involve considerable long-term protection and care, perhaps in designated garden spaces where a variety of plants from different habitats are brought together. Sowing, too, can range from the casual broadcasting of mature seed at the time of harvest to sowing in new locations or even new habitats, perhaps in combination with soil tillage for seed bed preparation and seed storage.

Following Harris (1989), agriculture derives from the Latin *ager*: field; and horticulture from *hortus*: garden. Both terms help to establish differences in the scale of cultivation and the kinds of plants grown in each system. Gardens are smaller than fields, and are more structurally and floristically diverse. They contain a greater diversity of plant forms and taxa, especially of perennial trees and shrubs, and unlike fields, they can be cultivated throughout the year. An important characteristic of gardens is that alongside the 'crops' a wide range of weedy and wild plants which have multiple uses are also grown. These semi-wild ecosystems therefore allow the hybridisation of new varieties (Harris 1989, 23).

Harris (1989) includes within agriculture the domesticated animals as part of the production system, defining pastoralism as systems of mobile livestock pasturing and differentiating

nomads from transhumants: the latter refer to seasonal movements of selected members of an agricultural village. In Atacama, the term 'transhumance' is not tied to agricultural villages (Núñez 1980; 1981a; 1981b; Núñez & Santoro 1988), and I will use 'agriculture' just to refer to plant management and farming as a way of obtaining food that involves cultivating plants and herding animals (Price & Gebauer 1995, 3).

Summary

In this chapter I have given a brief discussion of the main approaches to the onset of agriculture and some of their applications in America. To explore the contexts under which communities would have changed in Atacama, I considered human reasoning within the concepts of risk-spreading strategies in the Andes. As a compliment to this, the reorganisation of subsistence patterns can be described and explored with evolutionary models and I have identified diverse concepts and categories regarding plant manipulation that are relevant to societies that sit in the 'middle ground' between hunter-gatherers and intensive farmers.

CHAPTER III. The western slope of the Puna de Atacama. Ecological and cultural background

Introduction

In this chapter, I will provide the main ecological, paleoenvironmental and cultural background of the area. More detailed and accurate information regarding the cultural and natural contexts of the sites from which the samples were taken will be given in Chapter VI and Appendix 2.

III.1 Ecological Background

-The western slope of the Puna de Atacama

This study takes place in northern Chile (22°, 55' S), in the Andean flanks of the Antofagasta Region, Loa Province (2200-5000masl). This highland (Figure 4) area is part of the Puna de Atacama, within it the western slope (Atacama Puna) and the eastern slope (Puna Jujeña) can be distinguish (Tarragó 1984, 93).



Figure 4. Western slope of the Puna de Atacama. Study area hatched. Adapted from (Cartajena *et al.* 2007, 158).

The western slope of the Atacama Puna rises from one of the driest deserts of the world – Desierto de Atacama - and is one of the most inhospitable and fragile Andean environments due to its extreme aridity and low temperatures (Marquet *et al.* 1998). Its low humidity is caused by the presence of the Pacific Subtropical Anticyclone and the Humboldt Current, as well as the Andean mountain chain that blocks the entrance of the humid air coming from the Amazonian Basin, although some rain passes through during the summer months. The amount of rain varies between 10mm in the basin and 400mm in the highlands, precipitating either as water or snow respectively.

Within this research, the sites sampled are located mainly in the oases and meadows, middle and low altitudes of ravines and rivers, from the Salar de Atacama and Loa subareas (Figure 5 and 6).

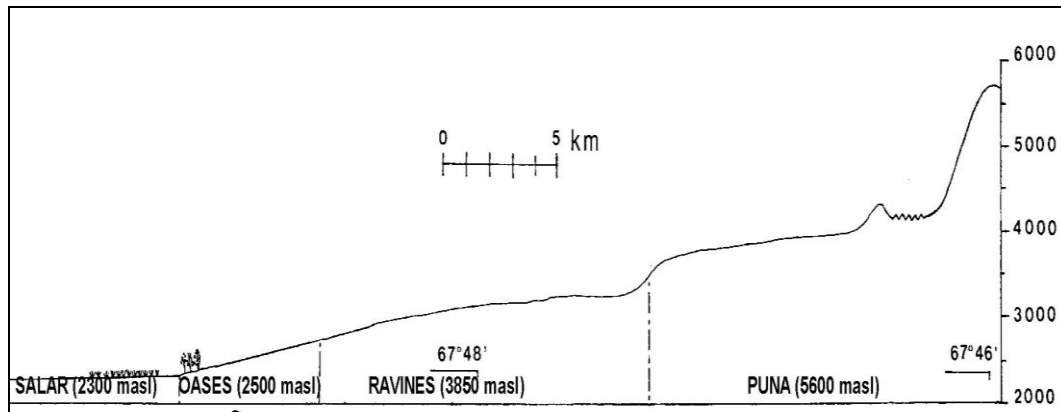


Figure 5. Geographical floors in the Atacama Puna. Adapted from (Dransart 2002, 171).

Figure 6. Oases, ravines, rivers and meadows ecosystems (courtesy of Eduardo Lira).

Sub-areas

The western slope of the Puna de Atacama can be divided into two subareas (Loa and Salar de Atacama) according to the main hydrological systems.

Loa Subarea

The Loa sub-area consists of the hydrological system of the Loa River and its tributaries (the San Pedro and Salado Rivers). The Loa River is the only exoreic course of the region, being not only a main corridor between the Andes and the Pacific Ocean but also a fertile riverside where human populations settled, practicing agriculture and herding as well as sustaining intense caravan traffic. It has been divided into the Loa Superior (4200-3200masl), Loa Medio (3200-2200masl) and Loa Inferior (2200-0masl) (Upper, Middle and Lower, respectively). It is mainly in the middle area where some sites have been sampled and where oases and meadows with a long history of human settlements have been registered (Calama and Chiu-Chiu, among others) (Figure 7).

Salar de Atacama sub-area

The Salar de Atacama is the main geographic element, occupying a surface of 100Km long by 80Km wide. The salt deposit is a result of the surfacing of underground waters saturated with mineral salts. This water accumulates due to the seasonal discharge of the ravines and rivers as well as from remnants of lagoons in it. The main water sources are the San Pedro and Vilama Rivers, which give life to San Pedro de Atacama oases and another twelve oases in the surroundings, at the northern shore of the Salar de Atacama. The San Pedro River is the main source of irrigation in the environs of San Pedro. Vilama is the second most important river and flows 5 Km towards the east of the former. It originates around 22 Km north of San Pedro town at 3370masl on the confluences of the Puripica and Puritama Rivers.

Other permanent and stationary ravines in the western slope of the Andes are generated by spring waters and rains. These are located at the south east of the Salar de Atacama (e.g. Jerez, Talabre, Camar, Peine and Tulan) and give life to several oases (e.g. Toconao, Socaire, Peine and Tilomonte), where agriculture and forest resources are provided and human settlements have long records (Figure 7).

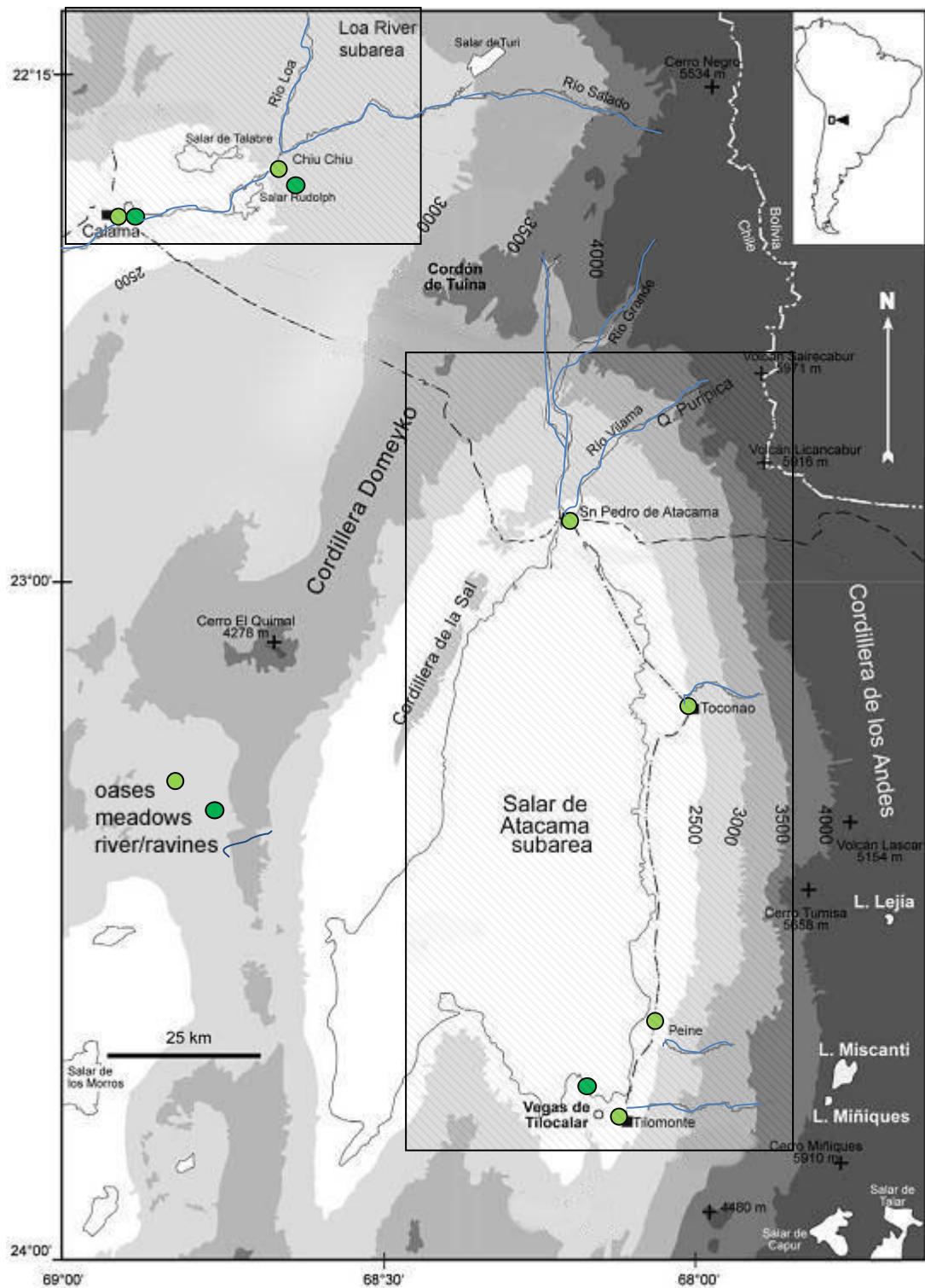


Figure 7. Subareas (Loa River / Salar de Atacama hatched) and ecosystems (oases, meadows, rivers/ravines) studied. Adapted from Latorre *et al.* (2003, 226).

Flora and fauna

The dry environmental conditions, with huge thermal oscillations between day and night, intense solar radiation and high evaporation, affect the distribution and vegetation cover. Therefore the values of vegetation density will be the lowest in the basis of the western slope of the Atacama Puna and highland extremes and highest in the middle altitudes (Villagrán *et al.* 1998b). The vegetation presents low diversity, which can be classified not exclusively but roughly according to different altitudinal belts that vary locally according to slope aspect and drainage (Figure 8) (Quade *et al.* 2007). The nomenclature followed for the vegetation belts is based on its structure and physiognomy (Villagrán *et al.* 1998a; Villagrán *et al.* 1998b; Villagrán *et al.* 1983).

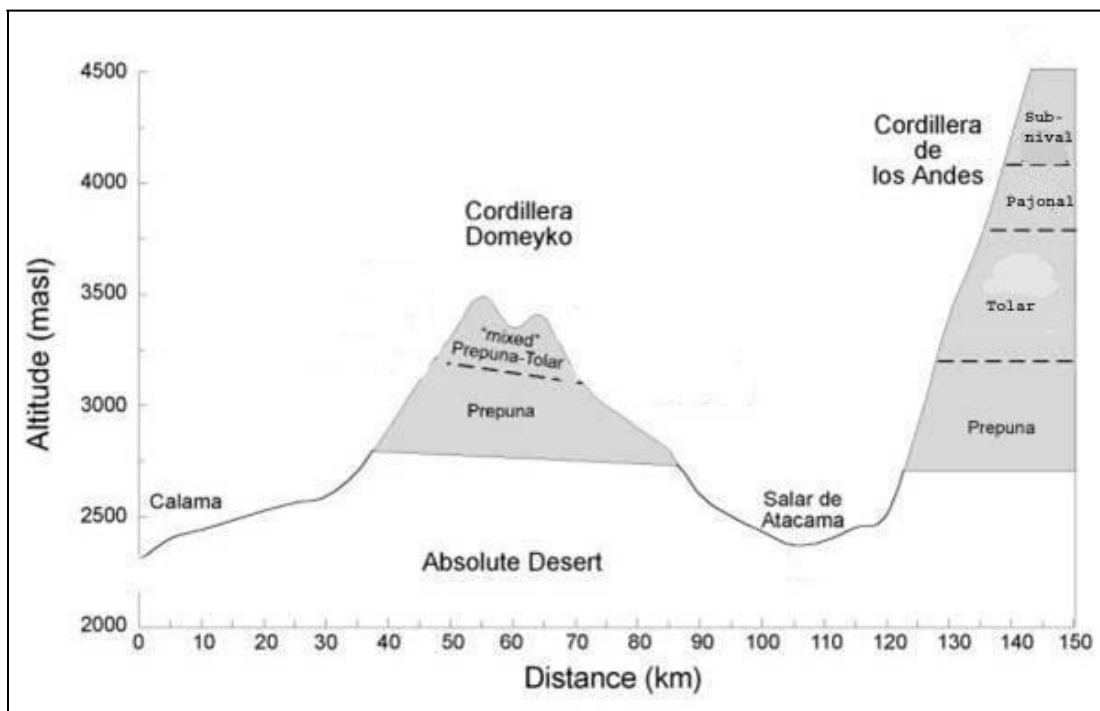


Figure 8. Diagram of vegetation belts. Adapted from Latorre *et al.* (2003, 227).

The eastern margin of the absolute desert grades into the Pre-puna (2600- 3400masl) and it is characterised by a low density and diversity. Shrub species such as *Ambrosia artemisioides*, *Atriplex imbricata*, *Krameria lappacea*, *Acantholippia deserticola*, *Adesmia atacamensis*, *Lycopersicon chilense* and *Tarasa operculata* as well as succulents *Cistanthe* sp. and cactuses from *Opuntia* and *Echinopsis* genera predominate above 2900masl. Then the Tolar belt (3400-4000masl) is the more diverse and dense in vegetation. Its main shrubs are

Baccharis boliviensis, *Baccharis tola*, *Fabiana ramulosa*, *Fabiana denudata*, *Adesmia erinacea*, *Lupinus oreophilus*, *Lampaya medicinalis*, *Junellia seriphioides*, *Ephedra breana* and *Chuquiraga atacamensis*. At 3800masl there is a transition to the Piso Altoandino or Pajonal (3800-4350masl). Cushion vegetation dominates sandy and gravelly terrains, with *Mulinum crassifolium*, *Pycnophyllum bryoides*, *Urbania pappigera*, *Nototriche estipulata*, *Adesmia subterranea*, herbs such as *Perezia atacamensis* and *Werneria glaberrima* and specially grasses of *Stipa chrysophylla*, *Nasella nardoides* and *Festuca chrysophylla*. Also Compositae family shrubs are abundant in the ravines and rocky slopes. Above 4350masl, the Subnival belt has a poor density of cushion vegetation, grasses and small herbs. Finally, there is the Azonal vegetation of salares, ravines and oases. The salares are interrupted by fertile oases composed by Fabaceae trees of *Prosopis*² (algarrobo) and *Geoffroea decorticans* (chañar), which predominate along with shrubs such as *Atriplex atacamensis* and a dense coverture of *Distichlis* grasses. Here different crops have been grown for centuries in the *chacras*, foreign species (alfalfa) predominate today though maize is still widely planted. The presence of water in the ravines, rivers, oases and salares allows green algae to grow, as well as palustrian species such as *Juncus arcticus*, *Scirpus sp.*, *Cortaderia atacamensis* and *Sarcocornia fruticosa*. At this low altitude, meadows have a less diverse composition than in higher cuotes, with species such as *Juncus balticus*, different species of *Distichlis* grasses (Villagrán & Castro 1997, 281) and *Scirpus californicus* predominating (Latorre et al. 2002).

² *Prosopis* species present significant variability within them and frequent hybridisations, which is why in Chile as well other countries there is significant confusion regarding native and cultivated species (Barros & Wrann 1992). Apparently *P. alba* and *chilensis* are currently present in Atacama (Benoit 1989; Cárdenas 1998; Núñez 1998; Vidal 2007; Villagrán et al. 1998a; Villagrán et al. 1998b). Contreras (1994) refers that in the area there are seven types, though he does not specify whether these are local perceptions or taxonomic differentiations. Mostny (1954) refers to two varieties of *Prosopis* in Peine, black and white, referring to the colour of their fruits. Other local classifications are made based on the sweetness of the pods and fruits (Mostny 1954; Villagrán et al. 1998a; Villagrán et al. 1998b). V. Quezada, CONAF engineer states that *P. alba* predominates and constitutes the native population (pers. com 2013).

The most relevant fauna in the area are camelids. There are wild guanacos (*Lama guanicoe*) and vicuñas (*Vicugna vicugna*) from which the llama (*Lama glama*) and alpaca (*Vicugna pacos*) would have been domesticated around 4800BP (Cartajena 1995; Cartajena *et al.* 2007; Hesse 1982a; 1982b; 1986; Núñez 1981a). The four species can interbreed, giving birth to hybrids (Mengoni & Yacobaccio 2006). Vicuñas are the smallest (35-50 kg), followed by the alpaca (55-65 kg), then the guanaco (80-130 kg), and finally the llama (80-150 kg), which is the largest (Mengoni & Yacobaccio 2006). The ethology of these camelids differs in some aspects. The guanaco is a browser and grazer and is tolerant to arid conditions, and hence they have more flexibility of habitats (0-4250masl) and the widest distribution in South America. Groups of guanacos are still seen around the Salar de Atacama. The vicuña is mainly a grazer and restricted to higher altitudes (3700-4800masl). The guanaco and vicuña were hunted for their meat, grease and hide (Mengoni & Yacobaccio 2006). The alpaca has been bred mainly as a fine-fibre producer, whilst the llama is the most versatile form, being a source of food, hide and fibre and also a pack animal.

Other animals such as birds and their eggs (*Phoenicoparrus andinus* and *jamesi*, *Pterocnemia pennata*, *Fulica* spp.), different rodents (*Abrocoma cinerea*, *Abrothrix andinus*, *Ctenomys* spp., *Chinchilla brevicaudata*, *Eligmodontia puerulus*, *Lagidium viscacia*, *Phyllotis xanthophyus*), foxes (*Pseudalopex griseus*, *culpaeus*) and freshwater fauna like the native fish *Basilichtys semitilus*, the snail *Littoridina loaensis* and two frogs *Telmatobius halli* and *Bufo atacamensis* could have contributed to the diet and other by-products.

Below 2200masl the desert becomes absolute until the coastal Andean range; where humidity from the Pacific Ocean provides better conditions for terrestrial life. Underground water tables and small ravines provide the necessary conditions for human settlements. Lomas vegetation characterises this area, with various genera of Cactaceae, and different shrubs and herbs. In contrast to the limited land resources, the sea is rich in nutrients and oxygen from the Humboldt Current or the Peru Coastal Current, which results in an abundant source of food. A rich fauna of fish, molluscs, crustaceans, echinoderms, tunicates and cephalopods, as well as sea birds and mammals, has furnished subsistence to a large human population (Llagostera 1979, 310).

Therefore flora and fauna as well as human activities and the possibilities of settlements are strongly determined by the different ecological belts and ecosystems within them (Table 2).

<i>Ecological belt:</i>	<i>masl</i>	<i>Azonal vegetation</i>	<i>Zonal vegetation (main taxa)</i>	<i>Animals</i>	<i>Main activities</i>
<i>Coastal range (Lomas)</i>	0-2000	Oases Quillagua (Loa mouth)	Lomas and sea plants	Marine Birds Guanaco Small mammals	Marine exploitation. Small agriculture, herding, hunting-gathering
<i>Desert</i>	1000-2600	Loa riverside, oases	Desert	Llama, Guanaco Small mammals Fish, Birds	Mining, trading
<i>Prepuna (Desertico)</i>	2600-3400	Oases Ravines Riverside Meadows	<i>Ambrosia artemisioides</i> , <i>Atriplex imbricata</i> , <i>Krameria lappacea</i> , <i>Acantholippia deserticola</i> , <i>Adesmia atacamensis</i> , <i>Lycopersicon chilense</i> , <i>Tarasa operculata</i> . <i>Cistanthe</i> sp., <i>Opuntia</i> and <i>Echinopsis</i> .	Llama, Guanaco Small mammals Fish Birds	Agriculture (maize, beans, cucurbitaceae), herding, hunting-gathering
<i>Puna (Tolar)</i>	3400-4000	Ravines Riverside Meadows	<i>Baccharis boliviensis</i> , <i>Baccharis tola</i> , <i>Fabiana ramulosa</i> , <i>F. denudata</i> , <i>Adesmia erinacea</i> , <i>Lupinus oreophilus</i> , <i>Lampaya medicinalis</i> , <i>Junellia seriphioides</i> , <i>Ephedra breana</i> , <i>Chuquiraga atacamensis</i> , <i>Opuntia</i> sp.	Llama, guanaco, vicuña Small mammals Birds Fish	Agriculture (pseudocereals, tubers, maize), herding, hunting-gathering
<i>Altoandino (Pajonal)</i>	3850-4400	Ravines Riverside Meadows	<i>Mulinum crassifolium</i> , <i>Pycnophyllum bryoides</i> , <i>Urbania pappigera</i> , <i>Nototriche stipulata</i> , <i>Adesmia subterranea</i> , <i>Perezia atacamensis</i> , <i>Werneria glaberrima</i> , <i>Compositae</i> and specially grasses <i>Stipa chrysophylla</i> , <i>Nasella nardoides</i> , <i>Festuca chrysophylla</i> .	Vicuña, llama, guanaco, alpaca Small mammals Birds Fish	Agriculture (pseudocereals, tubers), herding, hunting-gathering
<i>Subnival</i>	4400-6000		<i>Deyeuxia cabreræ</i> , <i>Junellia digitata</i> , <i>Lenzia chamaepitys</i> , <i>Chaetanthera revoluta</i> .	Vicuña, alpaca Birds, Fish, Small mammals	Hunting

Table 2. Different ecological belts and main resources from the coast to the highlands.

-Paleoenvironment

Evidence from paleo-climatic records on the western slope of the Puna de Atacama (lat 22°–24°S) comes mainly from pack-rats; sedimentary and pollen records from highlands lakes and the Salar de Atacama, paleo-wetland deposits; alluvial records in ravines and archaeological sites over time. The paleoenvironmental sequence shows alternatively a

series of humidity and drought events, which have triggered a debate especially around the arid or humid conditions of the Middle Holocene (ca.8000-3000BP). Most of the proxies obtained in Atacama recall the Middle Holocene, being less information for the Late Holocene and the Formative period (ca.3000BP and afterwards). The Middle Holocene is conceived either as a relatively humid or an arid phase against which the character of the Late Holocene phase has been defined.

In this sense, proposals of an arid Middle Holocene and a subsequent more humid phase are given by Valero-Garcés *et al.* (1996) based on a core in Laguna Miscanti. They state that prior to 3900BP, levels of the lagoon were considerably lower than today, starting to rise between 3900 and 3000BP, suggesting a clear link between the increased effective moisture of the Late Holocene period and the human occupation in the area (Valero Garcés *et al.* 1996, 19). Geyh *et al.* (1999) also suggest that the Middle Holocene is characterised by a period of aridity based on the paleo-records of lake levels. In this same line, Grosjean *et al.* (1997), based on sedimentary flows and cultural occupations in ravine Puripica, propose that after 3000BP, precipitation rates increased and reached modern levels. In other papers, Grosjean *et al.* (2003; 2001) establish from water levels at Laguna Miscanti that there was an extremely arid Mid-Holocene and that modern conditions allowed the occupation of the area around 3000-3800BP. This trend towards major humidity may have started earlier due to carbon reservoir effects on radiocarbon dates (Latorre *et al.* 2006). Also Nuñez *et al.* (1995) propose a moisture trend around 3000BP, which is confirmed by the change in the hydrological regime of the Puripica River. Núñez *et al.* (2002) record Late Archaic sites by 3700-3300BP in Capur and Ollague, suggesting that this presence coincides with the recovery of the lake levels after the dry Mid-Holocene. Therefore a reflection of the changing environmental conditions would be that early sites are located along paleo-shores distant from modern resources, whilst late sites are located in modern shorelines and near subsistence resources (Núñez *et al.* 2002, 822). The rise in human occupation after the Late Archaic or in the Late Holocene would represent the end of drought conditions (Núñez *et al.* 1999). The absence of archaeological sites or the 'archaeological silence' through the Middle Holocene has also been interpreted as evidence for very arid conditions south of the Loa subarea, although intermittent evidence suggests human migration in search of available

resources and eco-refugees (Núñez & Grosjean 1994; Núñez *et al.* 1995; Núñez & Santoro 1988).

Defending a wetter Early and Middle Holocene and a not so “optimal” Late Holocene are Messerli *et al.* (1993). Their interpretation is based on a multidisciplinary approach involving the calibration of a wide range of proxy-data (pollen profiles, stratigraphic sequences in highlands lagoons and paleohydrologic evolution from the oases to the highlands) between latitudes 22° and 25°LS in northern Chile (Messerli *et al.* 1993). They propose that the Early Holocene (11000-7000BP) experienced wetter conditions and summer temperatures 3.5°C higher than today, providing favourable conditions for an early hunter-gatherer economy. These wet conditions were followed by a period with higher temperatures than before (between 6000-3000BP). However, they state that after about 3000BP, conditions became even drier, establishing the prevailing arid climate. Rech *et al.* (2002) measured the water tables of three hydrologic systems of the area since the Early Holocene. They concluded that an episode of high water tables (15400–9000BP) was followed by an episode (8000–3000BP) of moderately high water tables, whilst during the periods from 9000–8000BP and 3000–0BP there was a significant reduction in groundwater discharge. Increases in groundwater are linked to an increase in the frequency of the South America Summer Monsoon. Betancourt *et al.* (2000), based on combined data from packrats and wet-land deposits, state that the periods between 9000 to 8000BP and after 3000BP are times when vegetation and groundwater tables approached modern levels, perhaps the driest episodes in the past 22000BP (Betancourt *et al.* 2000, 1544). A similar signature was found in a core in the Salar de Atacama (Bobst *et al.* 2001). According to Latorre *et al.* (2003), based on rat middens, records infer a climate wetter than today from 76000-3200BP and a short wet interval probably between 1800-1200BP. Abrupt onset of dry phases (as the present hyperarid climate) occurred from 3200BP to the present. The authors propose that the end of the ‘archaeological silence’ (3400BP) was not determined by the end of an arid phase but due to the diffusion of technologies such as camelid domestication.

Other later proxies are not available. References to a drier event around 2000BP have been constantly proposed by archaeologists due to the abandonment of Tular and the shift in settlement pattern from the north-western oases of San Pedro to the southern and eastern

parts (Barón 1986; Llagostera *et al.* 1984; Llagostera & Costa 1999). In this sense it seems that after 2000BP, arid conditions were more pronounced and dunes advanced over this area. This arid period seems to be related to the upwelling of cold waters in the Pacific after 5000BP, which would increase the dryness in the coast and highlands, which nowadays are just fed by summer tropical rains without further recharges (Romero *et al.* 1993).

Regarding paleo-flora, there are scarce pollen records, especially for the oases, where crucial resources for human subsistence now grow. A pollen profile from Tumbre in Talabre ravine (3880masl); shows environmental evolution since 7500BP when wet conditions were followed by a period with higher temperatures (ca.6000-3000BP). After 2200BP, a fundamental change in environmental conditions is evident from the Talabre pollen profile, though the effect of intensive pastoralism on the abrupt change in vegetation is not yet clear (Messerli *et al.* 1993, 125). Maldonado *et al.* (2005) based their pollen analyses on packrats (2670–3500masl), identifying common taxa and vegetational formations similar to those present today, although their altitudinal limits shifted according to wetter or more arid phases. Also, as I reviewed above, macro-flora remains from packrats are abundant for the lower limits of vascular plants and above (Betancourt *et al.* 2000; Holmgren *et al.* 2001; Latorre *et al.* 2002; Latorre *et al.* 2003).

Nevertheless, neither *Prosopis* nor *Geoffroea decorticans* are recorded in these proxies. Kalin Arroyo *et al.* (1988) states that *Prosopis* is a survival of the lowland Pliocene vegetation at Atacama. Nester *et al.* (2007) report the presence of *Prosopis* since the Pleistocene though northeast from the area of study, at Pampa del Tamarugal (21° 14'; 69° 40'; 1000-1100 masl). These remains are present only in two wetter events, the first one (as pollen) around 16380 to 13740 cal yrBP, during the latest Pleistocene, and a second event that occurred during the Holocene, when phreatophytic trees also grew in these drainages as different macroremains shows (seeds, leaves, inflorescence, twigs) between 1070 and 700 cal yrBP, during the Medieval Climatic Anomaly (Nester *et al.* 2007, 19724). Gayo *et al.* (2012a) confirm this Late Holocene presence of *Prosopis*.

For this later period ethno/historical sources allow us to reconstruct to some extent the oases' vegetation prior the effects of industrial change. Documents suggest that the population of *Prosopis* and *Geoffroea decorticans* trees were very abundant when the

Spaniards arrived in the area. Bibar (1966 [1558]) pointed out that the Indians hid in these forests when the Spaniards intruded. Uhle (1913) describes that a wide area now covered with farming fields was covered in ancient times with these trees, which were a main staple for their inhabitants. Frezier in 1714 (cited in Núñez 1962) observed a big forest of *Prosopis* near Calama, which is now non-existent. Le Paige (1974) also mentions evidence of an extinct forest in Tchaputchaina. During colonial and republican times, they were strongly exploited for the mining industry, greatly depleting the original tree population (Boman 1908, 714). The archaeological findings regarding these trees are discussed later (Ch. V), though their presence cannot be considered merely as an indicator of natural environment due to the cultural factors mediating their planting, protection and felling. Examples of the modifications that the present vegetation might have suffered, especially due to anthropogenic actions, are numerous. Dransart (2002) states that overgrazing by goats and sheep might have affected the original grasslands: “because present day conditions are markedly changed, it is my opinion that ethnographic analogies based on the present day exploitation of pasture in the Atacama should be used with great caution” (Dransart 2002, 167). She also cites Popper (1987), who describes an example of ecological imbalance of the rodents that feed in root grasses, which was probably caused due to the over-killing of felines by humans or the end of rodent consumption by humans. Fires to encourage new shoots, replacement of native by exotic flora and fauna and the extraction of the waters for mining activities and urban centres have certainly modified the pre-Columbian landscape.

III.2 Archaeological Background

Regarding the relationship between natural and cultural sequences, the Middle Holocene (8000-3500BP) is correlated with the Middle Archaic (ca.8000-5500BP) and Late Archaic (ca.5500-3500BP) periods, characterised by hunter-gatherers settled in eco-refuges, which developed early complexity and camelid domestication. The Late Holocene (3500BP- 0BP) is correlated to the Formative period (ca.3000BP-1500BP) and afterwards developments of the Middle period or Tiwanaku influences (ca.1500-1000BP), Desarrollos Regionales (ca.1000-500BP) and Inka presence (ca.500-400BP). Hence, with some particularities and time-lags, the cultural development of the communities settled in the western slope of the Puna de Atacama are part of the general Andean cultural scheme (Núñez 2007), in which

archaic hunter gatherers transit to more sedentary agro-pastoralists; gradually increasing their complexity through the intensification of new productive forms and exchange, generation of surplus, demographic stability, consolidation of cultural identity and higher levels of political control.

Here I will give a general review of the Late Archaic and Formative cultural periods (dates refer to general ranges for periods. These might vary depending on specific dating for sites) (Table 3).

<i>PERIOD</i>	<i>Subsistence pattern</i>	<i>Local Phases</i>	<i>Area/locality</i>	<i>Ecosystem*</i>
LATE ARCHAIC (5400-3800BP) (3500-1850BC)	<i>Complex hunter-gatherers</i> <i>Semi-permanent hunting/gathering and herding (transitional stage towards pastoralism and horticulture?)</i>	<i>Chiu Chiu</i>	<i>Loa/Chiu chiu, Kalina</i>	<i>River/oases meadows</i>
		<i>Ghatchi</i>	<i>Salar de Atacama/Vilama</i>	<i>River/ravine</i>
		<i>Tulan</i>	<i>Salar de Atacama/Tulan</i>	<i>Ravine</i>
		<i>Puripica</i>	<i>Salar de Atacama/Puripica</i>	<i>Ravine</i>
3800-3000BP 1850-1400BC	<i>Transitional</i>	<i>Tarajne</i>	<i>Salar de Atacama/Tulan</i>	<i>Ravine</i>
EARLY FORMATIVE (3000-2350BP) (1400-400BC)	<i>Semi-permanent, permanent hunting/gathering herding and horticulture?, social stratification, increasing interaction, ritual manifestations beginnings of craft production (pottery, mining, textiles)</i>	<i>Vega Alta I-II</i>	<i>Loa/Chiu Chiu</i>	<i>River/oases meadows</i>
		<i>Chorrillos</i>	<i>Loa/Calama</i>	<i>River/oases meadows</i>
		<i>Ghatchi</i>	<i>Salar de Atacama/Vilama</i>	<i>Riverside</i>
		<i>Tilocalar</i>	<i>Salar de Atacama/Tulan</i>	<i>Ravine/meadows</i>
LATE FORMATIVE (2350-1500BP) (400BC-500AD)	<i>Semi-permanent, permanent hunting/gathering herding and agriculture? social stratification, mature manufactures and surplus production. Strong interaction. Cemeteries, villages. Classic Atacameño</i>	<i>Loa I-II</i>	<i>Loa/Loa</i>	<i>River/oases meadows</i>
		<i>Chorrillos</i>	<i>Loa/Calama</i>	<i>River/oases meadows</i>
		<i>Toconao/Sequiton</i>	<i>Salar de Atacama/San Pedro</i>	<i>Oases</i>
		<i>Tilocalar 3</i>	<i>Salar de Atacama/Tulan</i>	<i>River/oases meadows</i>
		<i>Calar/ Puripica</i>	<i>Salar de Atacama/Puripica, Vilama</i>	<i>River/Ravine</i>

Table 3. Local phases and their chronological, cultural and spatial characteristics (*See Table 2 for ecosystem characterization).

-Late Archaic (5400-3800BP / 3500-1850BC)

During this phase, the ravines and riversides have a stronger occupation than the oases, especially in the Salar de Atacama area. These occupations are settled in the Loa River,

Vilama River, Puripica and Tulan ravines. The most described and studied sites of this period are Tulan 52, Puripica 1 and Puripica 3, Calarcoco 3, Ghatchi 2C, Ghatchi 02Vi90, Ghatchi 2B in the ravines of the Salar de Atacama; and Kalina Los Morteros and Ranl (various sites) on the Middle Loa (Agüero 2005; Aldunate *et al.* 1986; Druss 1976; Núñez *et al.* 2006; Núñez *et al.* 1999; Núñez *et al.* 1995; Serracino 1985); some of these are sampled within this research (Figure 9). These semi-permanent sites have been used to characterise wider cultural complexes: Tulan, Puripica and Chiuchiu, which seem to be interrelated (Aldunate *et al.* 1986; Druss 1976; Mena 1984; Núñez 1981a). Other sites have been poorly described and/or do not have the visibility of the former.

The Late Archaic tradition is characterised by quarries, lithic extraction areas and campsites, which vary from small to large settlements, the development of solid architecture formed by multiple agglutinated circular stone structures, a diversified and innovative lithic industry with microliths and perforators, reduction in mobility, the appearance of rock art, long-distance interactions and a transhumant subsistence strategy including foraging, but mainly hunting of camelids and later domestication. All of this suggests the development of an increasing sociocultural complexity (Cartajena *et al.* 2007, 4) and is in tune with the development of complex hunter gatherers within the Atacama Puna (Hocsman 2002; Muscio 2001; Olivera 1998; Yacobaccio 2006). Cultural materials that characterise this period are camelids and to a lesser extent small mammal bones, plant debris, lanceolate points with different variants, knives, scrapers, preforms, conical mortars and *manos*. It is during this period that early crops (*Lagenaria* sp. and cf. *Zea mays*) are appearing in the area (Bittmann *et al.* 1978; Le Paige 1975; McRostie 2007; Núñez *et al.* 2009). In the Middle Loa, an intensification of plant processing has been proposed due to the rise in numbers of grinding tools (Jackson & Benavente 2010).

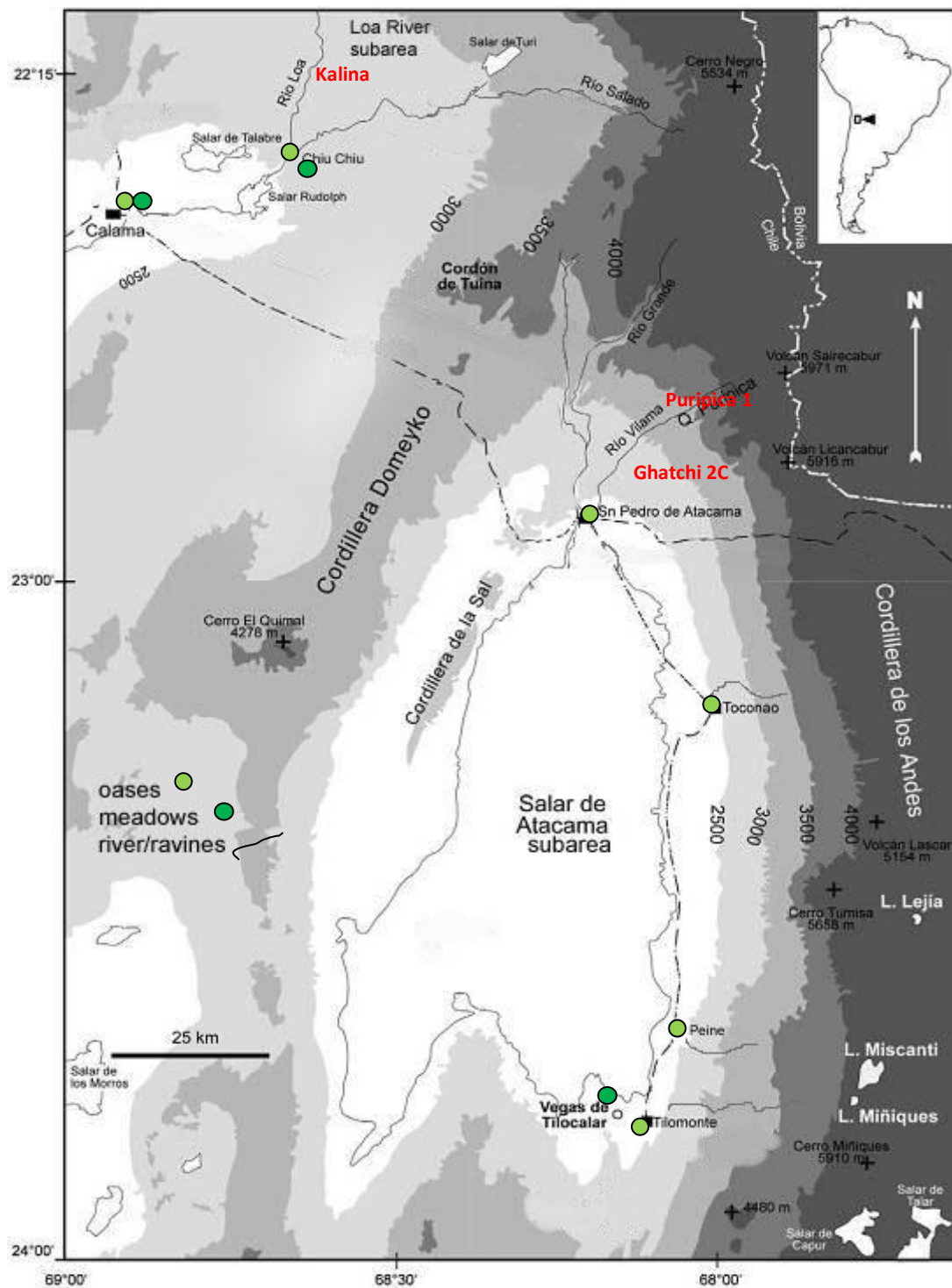


Figure 9. Late Archaic sites sampled for this thesis. Adapted from Latorre *et al.* (2003, 226) .

In between the Late Archaic and the Early Formative, a transitional phase, “Tarajne” (1850-1400BC) has been defined in the Tulan ravine within Tulan 94 and Tulan 122 sites (Núñez *et al.* 2002-2005). However, its extrapolation is not clear for other areas of the western slope of the Puna de Atacama and hence it will not be discussed further within this research.

-Formative (3100-1500BP/ 1400BC-500AD)

The Formative development shares considerable attributes in the Salar de Atacama and Loa area. This period has been subdivided into three sub-periods, Early, Middle and Late Formative for the San Pedro oases and Middle Loa, though in the southern edge of the Salar in Tulan, it has just been divided into the Early and Late Formative (Table 4).

<i>Formative</i>	<i>ca. Years</i>	<i>LOA</i>		<i>SALAR</i>		
		<i>Chiu Chiu</i>	<i>Calama</i>	<i>Vilama</i>	<i>San Pedro oases</i>	<i>Tulan</i>
<i>Early</i>	<i>1400-400BC</i>	<i>Vega Alta I-II</i>	<i>Chorrillos</i>	<i>Early</i>	<i>Early</i>	<i>Tilocalar</i>
<i>Middle</i>	<i>400BC-100AD</i>	<i>Loa I</i>		<i>Toconao</i>	<i>Toconao</i>	<i>Late</i>
<i>Late</i>	<i>100-500AD</i>	<i>Loa II</i>		<i>Sequiton</i>	<i>Sequiton</i>	<i>Late</i>

Table 4. Denomination for different phases of the Formative period in different areas.

-Early Formative (3000-2350BP/ 1400-400BC)

Within the Atacama Puna, the Early Formative period has been characterised locally: thus the denominations vary according to site-type nomenclature. Therefore, in the Tulan ravine has been defined as Tilocalar (Núñez 1992; 1994; Núñez *et al.* 2006), in the San Pedro oases and Vilama River as Early Formative (Agüero 2005), in the Middle Loa as Fase Vega Alta I and II (Pollard 1970; 1971), as Los Morros in the Salado River (Sinclair 2004) and in the Calama oases as Chorrillos (González & Westfall 2006). Most of the sites of this period in the meadows, oases and ravines are better characterised as semi-permanent occupations. Similar to the Late Archaic settlement pattern, the major and most relevant sites in the Salar de Atacama during this period are located in the ravines and rivers rather than in the oases. These settlements are more related with a hunting, gathering and herding tradition which is still not fully sedentary (Agüero 2005; Agüero *et al.* 2009; Núñez *et al.* 2006; Núñez *et al.* 2009). The main developments of this phase have been inferred from Tilocalar phase found in the southeast of Salar de Atacama in the Tulan ravine. Here a series of sites, including the dense habitation site of Tulan 85 in Tilocalar meadows and the ritual site of Tulan 54, set up the appearance of a complexity without precedents. These sites have been used for defining the indicators of this stage. Sophisticated offerings, rock art, domestic camelids and material culture in general reflect a developed herding society from a local Late Archaic tradition (Núñez 1994; 2005; Núñez *et al.* 2006). Other sites in the ravine appear more

transitory (Tulan 122, 55, 67), although they are part of the settlement pattern of these developed hunter-gatherers and herders with the presence of scarce crops.

In the north area of Salar de Atacama, this phase is nucleated in the Vilama river, in sites such as Ghatchi, associated with the San Pedro oases' non-structured and dispersed sites (Po-18; Po-25; Po-12 and Tchaputchayna), both with their roots in Late Archaic traditions (Agüero 2005; Agüero *et al.* 2009). The ravine sites at the north of the oases exercised control over them due to their location on an important path and exchange route between San Pedro, the Loa River and the highlands. This character is manifested in the ceremonial constructions similar to Tulan (Agüero *et al.* 2009, 325). These sites are interpreted as small-scale herding and hunting-gathering societies, whose seasonal nature led to ephemeral occupations related with the adaption of this subsistence pattern (Agüero & Uribe 2011).

In the Middle Loa (Vega Alta I-II), agglutinated and non-agglutinated semi-permanent campsites with hunting, gathering and initial herding economy predominate and interact in a regional and extra-regional range. Evidence of domestic llamas has been reported from around 900BC in Chiu Chiu 200 (Benavente 1988-1989) or 500BC (Pollard 1971). These camps were settled near a wide system of meadows and oases suitable for grazing of the animals as well as utilisation of forest resources. Based on a series of cultural indicators, this population has been interpreted as the arrival of new population groups (Benavente 1982), which differs from the previous Late Archaic Chiu Chiu Complex, though for Pollard (1971) these changes have been interpreted as an autoctonus evolutionary development.

Common traits for the Early Formative period are the emergence of new technologies such as Los Morros pottery, described as a stylistic horizon that originates from the highlands (Uribe 2003; Uribe & Ayala 2004); copper and to a lesser extent gold metallurgy, textiles, micro-drills, lithic hoes, flat grinding stones (complementing conical mortars) and crops (*Lagenaria* sp., *Zea mays*, cf. *Chenopodium quinoa*). Also, several indicators reflect an increase in the contact with Northwestern Argentina (e.g. Cultura San Francisco, Vaquerías, Ciénaga), the Meridian Highlands (e.g. Lipez, Chiripa, Wankarani) and the Tarapacá coastal valleys (e.g. Guatacondo). Beyond particularities, which have been defined for each locality based on the main site studied (e.g. Chorrillos, Vega Alta I-II, Tilocalar, San Pedro oases), evidences for hunting and gathering activities predominate, with a gradual and

differentiated incorporation of herding and horticulture which are thought to have increased through the Formative period (Agüero 2005; Agüero & Uribe 2011; Agüero *et al.* 2009; Núñez 2005; Vidal 2007). For Agüero *et al.* (2009, 325), these societies were “all with a transitional economic organisation”.

Some of the most studied and visible sites are Tulan 54, 55, 122 and 85, Chiu Chiu 200, Chorrillos and Ghatchi 2C, which were sampled for this thesis (Figure 10).

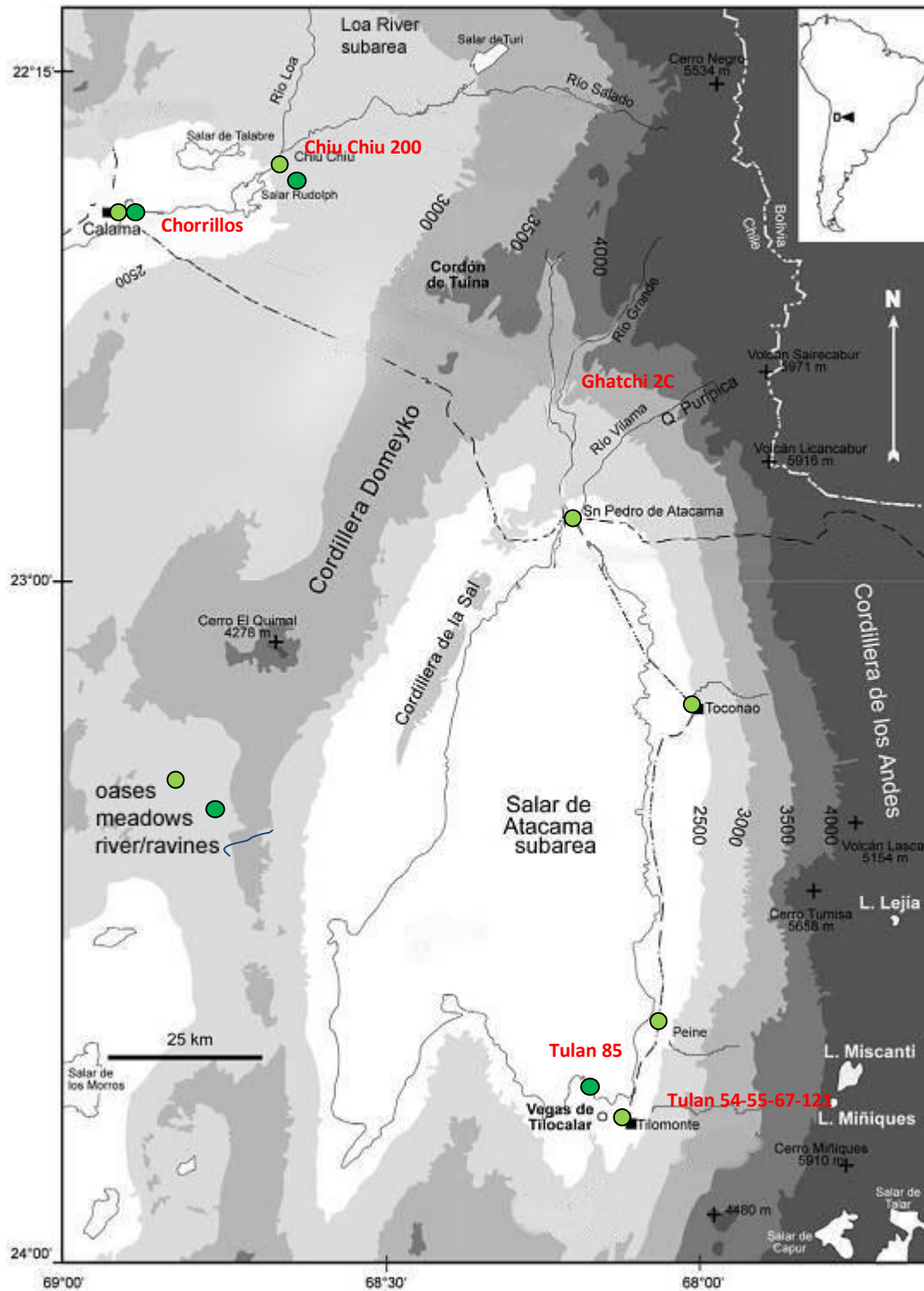


Figure 10. Early Formative sites sampled for this thesis. Adapted from Latorre *et al.* (2003, 226).

-Middle and Late Formative (2350-1500BP/ 400BC-500AD)

In the southern edge of the Salar de Atacama in Tulan, this period is commonly named as the Late Formative (500BC-500AD). In the northern edge of the Salar de Atacama in San Pedro oases and the Vilama River, it is divided into the Middle and Late Formative periods³ (Agüero 2005). Here the Middle sub-period is known as Toconao (500BC-100AD) and the Late Formative as Séquitor (100AD-500AD) (Berenguer *et al.* 1988; Tarragó 1989). In the Middle Loa, Pollard (1971) has defined the Loa I Complex (200BC-100AD) and Loa II (100-300AD), and in the Salado River the Formative expands from 500BC until the Late Intermediate period (Sinclair 2004).

In Tulan, larger semi-permanent and permanent sites were abandoned, being replaced by smaller ones (Tulan 71, Tulan 82, Tulan 59, Tulan 57) or by less dense re-occupations (Tulan 85), suggesting that the core of the population would now be in the nearby oases (Tilomonte, Peine, Toconao) and in the San Pedro oases, where an agrarian political centre was established (Núñez 2005; Núñez *et al.* 2006). It has been hypothesised that ravines' and oases' ecosystems were complementary, providing camelids and agrarian resources (maize) respectively, although the agrarian sites in the oases have not yet been found (Núñez 2005).

During the Toconao phase, in the northern area of the Salar de Atacama, the sites in the oases increase in number with respect to the nearby riversides and ravines in Vilama, although in the latter there are still important sites such as Ghatchi and Calar which reflect a common architectural background with the oases and with the Circumpuna population, particularly with the Southern Highlands and North-western Argentina (Llagostera *et al.* 1984; Orellana 1984). Non-structured sites start to occupy the central oases such as Larache and Yaye, but the sites of this phase are mainly located on the north-western edge of the San Pedro de Atacama oases, an area that during this period was presumably seasonally

³ As this later division is less clear and is just for the oases, I will follow Núñez's definition for the Late Formative in the interpretation of my data.

flooded with the waters of the river San Pedro, establishing meadows, lagoons and humid soils, which have been closely related to maize horticulture (Llagostera & Costa 1999). In this sense, Tulo 1 village is the best studied site of this new socioeconomic formation of horticultures. Although it has been described as a sedentary agro-pastoralist village (Barón 1986; Llagostera *et al.* 1984), for other authors the sedentary nature of this site is not clear (Dransart 2002). Also, recent research emphasises the role that forest resources might have in this village (Agüero 2005; Agüero *et al.* 2009; Vidal 2007). Except for Tulo 1, most of the sites found in the oases during this period are cemeteries (e.g. Larache Acequia, Sequitor Alambrado-Acequia and Toconao Oriente) and therefore it is hard to understand the role of Tulo or the degree to which this site represents wider social organisation. Among these cemeteries, Toconao Oriente is located more to the south-eastern edge of the Salar de Atacama, and has been used to discuss the complexity and changes seen during this phase. For Agüero and Uribe (2011), the evidence of this cemetery, such as the offerings and the stylistic change in pottery, among other artefacts, represent reinforcement of identity but not of sedentary agriculture populations, as previously stated (Tarragó 1989). They rather interpret the base of this period as “a slight displacement in the hunting and pastoral economic systems in favour of another with emphasis on gathering and horticulture, promoting a surplus production and the development of manufactured goods to maintain control over the complementarity of their environment through internal trade” (Agüero *et al.* 2009, 325). Therefore herding was concentrated in the Vilama, Tulan and other ravines whilst it is suggested that gathering and the initial horticulture of maize was practiced in the oases (Agüero & Uribe 2011).

Indicators of this stage are the projectile points that become smaller, pendants, copper beads, *tembetás* and symbolic features, such as mazas and axes, which become popular. Drills are still important but they become bigger and more varied. The appearance of Sequitor drinking cups is usually interpreted as being used in *chicha* consumption and the necessity to strengthen horticultural practices and increasing social interaction. Scarce maize cobs, *Lagenaria* rinds and cf. *Chenopodium* have been recovered. Strong links with migrations from more distant areas such as Bolivian Highlands, North Western Argentina and the Pacific have been proposed due to similar characteristics of the architectural

patterns, the presence of *Strophocheilus oblongues* and other exotic molluscs as well as pottery variability (Loa Cafe Alisado (LCA), Loa Rojo Alisado (LRA), Sequitor (SEQ), Toconao (TOC), Vaquerías (VAQ) and Los Morros (LMS) (Adán & Urbina 2007; Agüero 2005; Barón 1986; Núñez 2005; Tarragó 1989), the latter characterized as foreign pottery related with the Bolivian Highlands (Wankarani y Chiripa) and the eastern slope of the Puna (San Francisco y Las Cuevas) (Sinclair et al. 1998; Uribe 2006).

The Séquitor phase (100-500AD) is when the major growth occurs in the oases as a prelude to the Middle period (Agüero & Uribe 2011). Tulo predominance declines, possibly due to drier climate conditions around 200AD (Llagostera & Costa 1999; Romero *et al.* 1993). Calar in Vilama is also abandoned. There is one village, Coyo Aldea, that only had a preliminary analysis, and it has been related to Tulo 1 and the agrarian and sedentary character of the oases villages during this period (Núñez 2005). The other habitational sites are discrete non-structured⁴ (ten sites in Beter, six in Cucuter and three in Poconche) and non-structured dispersed sites (five sites in Beter and one each in Poconche, Cucuter, Yaye and Sequitor) as well as cemeteries (Agüero 2005). People moved their occupation towards the upper course of the San Pedro River and almost all over the Salar de Atacama oases and their surroundings. This distribution could suggest a more intensive use and management of water of the Vilama and San Pedro Rivers for irrigation canals and crop fields (Llagostera & Costa 1999). The San Pedro oases becomes a significant population centre composed of several gathering and horticultural communities. It is proposed that this marks a transition to two complementary economies one “based on hunting, herding, and gathering practices, and another economy based on gathering, horticulture, and artisan production” (Agüero *et al.* 2009, 325). In this sense, the coexistence of groups in the ravines and oases represents

4 Non structured settlement: cluster of evidences that indicate different degree of occupation and territorial permanence from minor to major complexity. A) Discrete: concentrated evidences in low frequencies and with low demographic and heritage value. B) Disperse: Evidences that eventually are part of a same settlement with discrete values (Agüero 2005, 33) (translated by V. McRostie).

complementarities between agricultural and herding activities, performed by the same or different ethnic groups (Adán & Urbina 2007; Agüero 2005; Llagostera & Costa 1999; Núñez 2005). Agüero and Uribe (2011, 76) propose that the complexity seen towards the end of the Formative period is not based in agriculture nor in the caravanning system, but in the specialisation of forest resources in the oases.

During this phase, the classical Atacameño culture emerges. The pottery is characterised by vessels with polished surfaces, Sequitor (SEQ), together with smooth Loa Rojo Alisado (LRA), and to lesser extent Loa Cafe Alisado (LCA) and Los Morros (LMS). Lithic hammers and textiles become important. The use of wood becomes highly specialised, being evident in psicotropic objects from different cemeteries and the recognition of different species of *Prosopis* within a site (Agüero 2005; Vidal 2007). In this sense a wood industry is proposed due to the presence of sanctuary objects, mortars, tubes and construction, which would reach its climax during the next period (Núñez 1962). Maize and cucurbitaceae are also present, though not in high quantities (Vidal 2007). Copper ornaments and wealth artefacts such as Pacific and Oriental shells are circulating, reflecting social negotiation.

In the Middle Loa, Phase I of the Loa Complex (ca.400BC-100AD) is characterised by herding, hunting and gathering, although an increase of sedentism is evident with respect to previous Vega Alta I-II. Nine semi-permanent sites would have supported 15-40 individuals. Most of them have remains of stone structures. The Loa II phase (ca. 100-300AD) has been interpreted as the beginning of 'the emergence of full sedentary life sustained by the development of maize agriculture' (Pollard 1971, 47). During this stage the population seems to have doubled. Herding and gathering continue, in addition to the development of maize agriculture. The seven sites of this phase present, among other features, "agricultural terraces and irrigation ditches and ruins of a historic period house" (Pollard 1971, 47). On the surface, 1506 sherds, 161 hoe blade fragments, nineteen *manos* and eight milling stones have been recovered, although it is estimated that at least three times this number were present at the site (Pollard 1971). At 55 cm depth, a large quantity of *Prosopis* seeds (some found within a human coprolite) were found, and for the first time, maize cobs. Seventeen intact maize cobs and fragments were recovered. This evidence supports the position that maize agriculture was not present along the Middle Loa before the middle of the Loa

Complex (105AD): “I here accept this date as the beginning of maize and irrigation agriculture in the middle Loa region” (Pollard 1971, 48). Among the most important and studied sites of the Late Formative are Tulan 57, 58, 82 and 85, Toconao Oriente, Tulo 1, Calar, Puripica 23, 31, Chorrillos and Ranl 100, 273, most of which are sampled for this thesis (Figure 11).

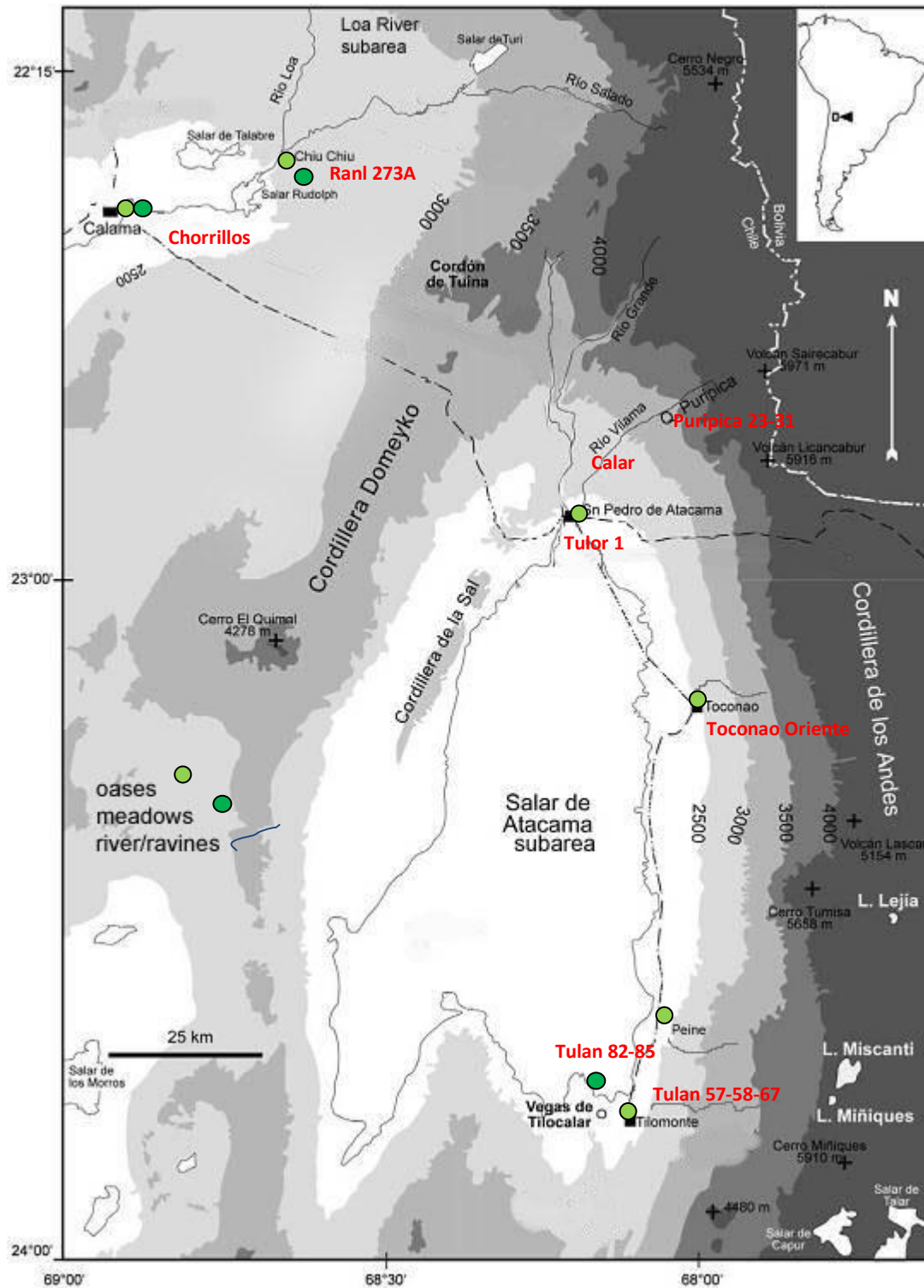


Figure 11. Middle and Late Formative sites sampled for this thesis. Adapted from Latorre *et al.* (2003, 226).

Summary

The western slope of the Puna de Atacama is located at the eastern limits of one of the driest deserts in the world. Here the summer rains as well as everlasting snow in the summits of the Andean range feed the two main hydrological systems of the Loa Province (the Loa River and its tributaries and the Salar de Atacama and the rivers and ravines that flow into it). Altitude is the main variable that affects vegetation distribution and density, except in areas where oases, meadows or ravines are present, creating distinct micro-zonal patches of vegetation (see Table 2). Unfortunately no pollen diagram or other plant proxy is available to determine the presence and coverages of species such as *Geoffroea decorticans* and *Prosopis* in the oases during pre-Columbian times. Much of the current vegetation found in oases and ravines might resemble the same flora and specimens that existed in the Formative, though their distribution and density might have been affected due to environmental variables but mainly due to overgrazing (by sheep) and other anthropomorphic interventions (fires, water extraction, and the introduction of new crops among others). The management of resources during the past might have domesticated the environment by favouring those species and specimens that people or herds consumed. Different crops also have specific altitudinal requirements and therefore are more suitable to cultivate in distinct environmental belts. Also wild and domestic fauna have their altitudinal ranges, which vary in relation to seasons and climate events.

Future analyses might allow us to achieve a clearer scenario concerning the discordance between paleoenvironmental records for the climate of the Atacama through the middle and late Holocene sequence. Most of the proxies obtained in Atacama relate to the Middle Holocene period with limited data for the climate of the Late Holocene. Therefore, the interpretation of a humid or arid Middle Holocene has been used as a parameter against which to compare the Late Holocene. Some authors support a wetter Middle Holocene and a Late Holocene with similar conditions to today (e.g. drier than before); others suggest a very dry Middle Holocene and a Late Holocene with similar conditions to today (e.g. wetter than before). Both positions have been used in the interpretation of cultural changes, giving different weight in the Late Archaic and Formative developments. We still need more proxies, especially pollen proxies, for the climate and vegetation of the Late Holocene and

Formative period, in order to have a better understanding of the climate and vegetation as well as their role in cultural change. It might be that the discrepancies in the records and interpretation are due to the different temporal and spatial resolutions of the diverse proxies (Grosjean *et al.* 2003).

Regarding the cultural sequence, the Late Archaic as well as the Formative period presents similar developments in the Salar de Atacama and the Loa River. Major changes are represented during the Late Archaic by complex hunter-gatherers with the domestication of camelids and the onset of more sedentary campsites in the Loa River and Salar de Atacama ravines. The Early Formative in the Loa and Salar de Atacama can be characterised primarily as a continuation of the Late Archaic strategies. Indeed, agglomerate and semi-agglomerate villages located near previous settlements on ravines and still with a semi-permanent pattern rely on hunting and gathering and only to a lesser extent on herding and perhaps horticulture. The major difference from previous Late Archaic groups is the incorporation of new elements such as pottery, crops, flat mortars, copper bead production and an emphasis on ritual activities.

During the Middle (Toconao 500BC-100AD) and Late Formative period (Sequitor 100-500AD) of the oases sequence, and Tulan (where both periods are characterised as the Late Formative: 500BC-500AD), a major shift has been proposed due to the occupation of the oasis sites at the same time that ravine sites start to decrease in number and relevance. Most of the oasis sites are in environments close to the Vilama and San Pedro rivers, which have been interpreted as more suitable for horticulture and gathering practices, though these habitation sites are scattered, non structured, with scarce cultural materials (Agüero 2005). The only exception is Tulo 1, interpreted as a dense agro-pastoralist village which has been used as a guide site for the interpretation of this period, although even here there is scarce evidence for macro remains of maize. Another village, though still understudied, is Coyo Aldea. Most of the large Formative sites in the oases are cemeteries. Tulo and Toconao Oriente have been used as evidence of agro-pastoralist development (Barón 1986; Llagostera *et al.* 1984) with the main herding complement on the ravines (Núñez 2005). However, recent re-evaluations have given more importance to gathering and horticulture communities in the oases and hunting/herding communities in the ravines (Agüero 2005;

Agüero *et al.* 2009; Vidal 2007). Both economies would have complemented each other with resources and networking, leading to the discussion about whether two distinct social groups coexisted exploiting complementing resources in the Salar de Atacama; one more closely linked to Archaic traditions and animal subsistence, settled in the ravines; and the other linked to the Formative innovations and plant subsistence, settled in the oases (Adán & Urbina 2007; Agüero 2005; Agüero & Uribe 2011; Núñez 2005).

In the Middle Loa, changes in technology, settlement patterns and the proven presence of maize and llama have led to the proposal of the gradual development of agropastoralist villages, which consolidated in the Loa II phase during the Late Formative, although before 100AD these villages relied mainly on herding and hunting/gathering resources. While there can be little doubt about the presence of some crop cultivation by this Late Formative phase, this thesis aims to provide a fuller analysis of what plants were being procured, produced and consumed from the Late Archaic to Late Formative in order to evaluate to what degree cultivated plants provided an important dietary contribution during each phase.

CHAPTER IV. Tracking the domestication and the entrance of crops in South America.

Introduction

Below I will review the main precedents for when and where crops appeared in South America. A special emphasis is given to the Western Atacama Puna and nearby areas (the highlands of Bolivia and Peru, Northwestern Argentina, the Chilean and Peruvian Pacific Coast and the eastern lowlands of the Andes) as well as to the crops whose archaeobotanical evidence is more closely related with the Andean Highlands and Atacama evidence so far. In this revision, I will normalize the nomenclature and sigmas given by each author⁵ (BC/AD, BP, cal, ca) to BP⁶ and refer to the type of macro and micro remain as stated. This synthesis does not pretend to be exhaustive, but it is intended to be representative of the diversity, timing and the state of research regarding the entrance and spread of crops in South America. This review aims to provide a background against which to compare and discuss the presence or absence of crops during the Formative in the Atacama.

Crop complexes

The beginning of crop geography was set with De Candolle (1884) in his famous book “Origin of Cultivated Plants”, where he discussed maize domestication, among other species. Later Vavilov (1992 [1940]), using a differential phytogeographic methodology, proposed that the geographical origin of a plant was in the areas where the greatest genetic diversity was present, although domesticates can originate in one area and then develop

⁵ See Appendix 1

⁶ Rough comparisons are made, standardising to BP by adding or subtracting 1950 to BC/AD to available dates.

their diversity in another (Smith 1998b). Harlan (1971) considered that South America was a non-centre of domestication, which means that different plants were domesticated in several distinct parts of this wide region through different time-scales. Still there are crops whose wild ancestors are not known or whose areas are too extended to determine one precise zone of domestication. In spite of the latter, the altitudinal ranges of the Andes reflect a conspicuous diversity of landraces which have been labelled differently by scholars. Hawkes (1989), for instance, classifies roots and tubers considering the phyto-geographical zones where they originated (Table 5).

<i>TROPICAL ZONE</i>	
<i>Manihot esculenta</i>	<i>manioc, yucca</i>
<i>Ipomoea batata</i>	<i>batata, sweet potato</i>
<i>Dioscorea trifida</i>	<i>indian yam</i>
<i>Maranta arundinacea</i>	<i>arrowroot</i>
<i>Xanthosoma sagittifolium</i>	<i>coco yam</i>
<i>Calathea allouia</i>	<i>topinambur</i>
<i>WARM TEMPERATE ZONE</i>	
<i>Arracacia xanthorrhiza</i>	<i>arracacha</i>
<i>Canna edulis</i>	<i>achira</i>
<i>Polymnia sonchifolia</i>	<i>yacon</i>
<i>Pachyrrhizus tuberosus</i>	<i>jicama</i>
<i>Mirabilis expansa</i>	<i>mauka</i>
<i>COOL TEMPERATE ZONE</i>	
<i>Lepidium meyenii</i>	<i>maca</i>
<i>Oxalis tuberosa</i>	<i>oca</i>
<i>Solanum tuberosum</i>	<i>potato</i>
<i>Tropaeolum tuberosum</i>	<i>mashua</i>
<i>Ullucus tuberosus</i>	<i>ullucu</i>

Table 5. The three phytogeographical zones in which the roots and tuber crops of the American tropics originated. Reproduced from Hawkes (1989, 484).

But the general consensus represents three main sub-regions for the origins of South American cultivated plants (Table 6): the Andean High Elevation complex, the Andean Mid-elevation complex and the Lowland complex (Harlan 1975; Pearsall 1992). Other crops that do not represent these areas are catalogued as non indigenous pre-Columbian plants (Pearsall 1992).

<i>HIGH ELEVATION COMPLEX</i>	
<i>Chenopodium quinoa</i>	<i>quinoa</i>
<i>Lepidium meyenii</i>	<i>maca</i>
<i>Oxalis tuberosum</i>	<i>oca</i>
<i>Solanum tuberosum</i>	<i>potato</i>
<i>Tropaeolum tuberosum</i>	<i>mashua</i>
<i>Ullucus tuberosus</i>	<i>ullucu</i>
<i>MID ELEVATION COMPLEX</i>	
<i>Amaranthus caudatus</i>	<i>amaranth</i>
<i>Arachis hypogaea</i>	<i>peanut</i>
<i>Bunchosia armeniaca</i>	<i>peanut butter fruit</i>
<i>Erythroxylum coca</i>	<i>coca</i>
<i>Lupinus mutabilis</i>	<i>tarwi</i>
<i>Pachyrrhizus ahipa</i>	<i>jicama</i>
<i>Phaseolus lunatus</i>	<i>lima bean</i>
<i>Phaseolus vulgaris</i>	<i>common bean</i>
<i>Psidium guajava</i>	<i>guava</i>
<i>LOWLAND COMPLEX</i>	
<i>Annona cherimolia</i>	<i>cherimoya</i>
<i>Annona muricata</i>	<i>guanabana</i>
<i>Ananas comosus</i>	<i>pineapple</i>
<i>Bixa orellana</i>	<i>achiote</i>
<i>Canavalia plagioperma</i>	<i>jack bean</i>
<i>Canna edulis</i>	<i>achira</i>
<i>Capsicum baccatum</i>	<i>chili pepper</i>
<i>Capsicum chinense</i>	<i>chili pepper</i>
<i>Capsicum frutescens</i>	<i>chili pepper</i>
<i>Capsicum pubescens</i>	<i>chili pepper</i>
<i>Carica papaya</i>	<i>papaya</i>
<i>Cucurbita maxima</i>	<i>squash</i>
<i>Gossypium barbadense</i>	<i>cotton</i>
<i>Inga feuillei</i>	<i>pacae</i>
<i>Ilex paraguariensis</i>	<i>mate</i>
<i>Ipomoea batatas</i>	<i>sweet potato</i>
<i>Manihot esculenta</i>	<i>yucca</i>
<i>Nicotiana rustica</i>	<i>tobacco</i>
<i>Nicotiana tabacum</i>	<i>tobacco</i>
<i>Persea Americana</i>	<i>avocado</i>
<i>NON-INDIGENOUS PRE-COLUMBIAN PLANTS</i>	
<i>Lagenaria siceraria</i>	<i>squash</i>
<i>Zea mays</i>	<i>maize</i>

Table 6. Proposed areas of origin of major South American cultivated plants. Reproduced from Pearsall (1992, 1993).

The High elevation Complex

This is the more self contained of the South American agricultural systems (Pearsall 1992, 196). It is defined by crops that originally grew more or less between 3000-3500masl in a cool temperate zone. It is mainly composed of different genera of tubers (*Solanum*, *Ullucus*, *Oxalis*, *Tropaeolum*) and pseudocereals (*Chenopodium*, *Amaranthus*).

Tubers

The centre of genetic variability for these tubers is in the Bolivian and the Peruvian Andes (Harlan 1975; Smith 1998b, 178; Vavilov 1992 [1940]).

Potatoes and their wild relatives occur in the enormous genus *Solanum*, which is said to have over two thousand species (Grun 1990, 40). Several authors agree that the centre of the domesticated potato is in the Andes although they refer to a wide area from Central Bolivia to Central Peru (Bukasov 1973; Grun 1990; Malagamba & Kalazich 2011; Spooner *et al.* 2005; Vavilov 1992 [1940]). From this centre, the potato spread to all of South America (Spooner *et al.* 2005), creating new centres of genetic diversity, such as in southern Chile (Montaldo 1974), where for some authors there is a secondary centre of variability of cultivated potatoes (Ames *et al.* 2008; Grun 1990). Even if the exact species that gave rise to the domesticated varieties of potatoes is not known, it will be from the diploid group of the *Solanum brevicaule* complex (Malagamba & Kalazich 2011). Hawkes (1990) suggests that the wild progenitor of *Solanum tuberosum* is *S. leptophytes*, native to the Andes Highlands, which gave rise to the original domesticated potato *S. stenotomum*. *S. stenotomum* then hybridised with *S. sparsipilum* to form *S. tuberosum*, which is divided into two subspecies: *tuberosum* and *andigena*.

The other tubers, oca (*Oxalis tuberosa*), ullucu (*Ullucus tuberosus*) and añu (*Tropaeolum tuberosum*), are little known outside the Andean range. However, because the preservation of tuber tissues in archaeological contexts is very poor, the earliest specimens have been found in very arid or anaerobic contexts, often outside their expected original range of domestication and more recently identified within further diverse contexts by using microfossil analyses (Table 7).

The best well-preserved macro-remains come from central coastal Peru, where twenty dissected tubers were found in stratum dated around 4000-3200BP in the trash middens of four archaeological sites in the Casma valley (Ugent *et al.* 1982a). Also in Peru but in the highlands at Tres Ventanas cave, *Solanum tuberosum* and *Ullucus tuberosum* were dated by 6950BP (Hawkes 1990). *Solanum tuberosum* is reported in Northwestern Argentina Puna (Huachichocana cave, Quebrada del Inca, Puente del Diablo and La Gruta 1) in strata dated around 4450-2450BP (Pearsall 2008). On the northern coast of Chile, potatoes are reported in Caserones during the Formative period (Núñez 1981b). Of these species, no archaeological specimen has been recovered in Western Atacama Puna, though ethnohistoric and ethnographic reports registered *Solanum tuberosum* as an important crop in the highlands of the area (Castro 2008).

There is little archaeological evidence for the use of oca (*Oxalis tuberosa*) in prehistory (Logan 2006). The earliest date is 9950-9450BP from the Guitarrero Cave (Pearsall 1992); though beans in this stratum were directly dated, giving earlier dates (Kaplan & Lynch 1999). Later presence as a depiction in a Tiwanaku and Chimu vessel has been reported by (Towle 1961). For *Tropaeolum* there is no archaeological data. *Lepidium meyenii*, an endemic highland crop of the Central Andes, is grown from Central Peru to Bolivia and North-western Argentina (Ochoa & Ugent 2001). It is a cold-tolerant crop, observed under cultivation at 4400masl (Pearsall 1989). *Lepidium meyenii* roots have been found in the Preceramic-Formative sequence (5050-750BP) of the Panalauca cave in the Junin department in the highlands of Peru. Their changes in mean diameter through the sequence suggest a domestication process that has been explained as a co-evolution of plant-animal domestication in which cf. *Chenopodium quinoa* will also be present (Pearsall 1989). Pearsall (2008, 1839) states that domestication of the diverse local Andean tubers, pulses and quinoa was likely underway before 7750BP.

Recently, starch grain analyses have proven to be diagnostic elements for identifying these important Andean staples (Cortella & Pochettino 1995). At the start of my research some tuber-like starch grains were found attached to lithic hoes in Atacama Puna at the Tulan 55 site thought to date to the Formative period (McRostie 2007), the characteristics of these starch grains do not resembles local wild tubers. Unfortunately this context could be

contaminated by upper levels. Babot (2004) reports oca, ulluco and potato in Northwestern Argentina from starch grains attached to nine tools dated around 5350-3150BP. Perry and colleagues (2006) report the presence of cf. *Solanum* sp. starch grains in grinding stones dating to 3600-4000BP at the Haynuma site in the southern highlands of Peru. Langlie (2011) identified carbonised parenchyma (plant storage tissue) of tubers during the Wankarani Formative period of the Bolivian Highlands.

Country	Area	Site/Complex	Taxa	Type	ca BP (oldest)	Reference
Peru	Coast	Tres Ventanas	<i>Solanum tuberosum</i>	macro	7000AMS	Hawkes 1990
Peru	Highland	Panalauca	<i>Lepidium meynii</i>	macro	5050	Pearsall 1989
Arg	Highland	Huachichocana, Inca Cave, Puente del diablo, La Gruta 1	<i>Solanum tuberosum</i>	macro	4450	in Pearsall 2008
Arg	Highland	various sites	<i>Oxalis tuberosum</i>	sg	4100	Babot 2006
Arg	Highland	various sites	<i>Solanum tuberosum</i>	sg	4100	Babot 2006
Arg	Highland	various sites	<i>Ullucus tuberosus</i>	sg	4100	Babot 2006
Peru	Highland	Huaynuma	Cf <i>Solanum</i> sp.	sg	4000	Perry et al 2006, 2007
Bolivia	Highland	Wankarani	cf. tuber type	tuber	4000	Langlie 2011
Peru	Coast	Buena vista	<i>Solanum</i> sp.	macro	4000	Duncan et al 2009
Peru	Coast	Buena vista	<i>Solanum</i> sp.	sg	4000	Duncan et al 2009
Peru	Coast	Casma	<i>Solanum tuberosum</i>	macro/sg	4000	Ugent et al 1982
Peru	Coast	Pampa Llamas, Moxeke	tuber type	macro	3735	Ugent et al 1986
Bolivia	Highland	Chiripa	cf. tuber type	sg	3000	in Logan 2006
Chile	Coast	Caserones	tuber type	macro	3000	Núñez 1981, 1982
Chile	Highland	Tulan 55	tuber type	sg	3000	McRostie 2007
Chile	Coast	Azapa 6	<i>Solanum tuberosum</i>	macro	2500	Erices 1975

Table 7. Normalised dates (BP) for the appearance of High Complex tubers (sg: starch grain).

Pseudocereals

Different varieties and species of pseudocereals are present in the Andean range throughout the Americas. Quinoa is cultivated above 1800masl, although there is a southern variety that grows at sea level (Planella & Tagle 1995). Chenopods are weedy plants that colonise disturbed habitats; therefore regional experts believe that Andean domestication arose from wild species that established in anthropogenic spaces. Wilson (1988) proposes, on the basis of genetic variation, that the heartland of domestication was in the South

Central Andes of southern Peru and Bolivia. This area coincides with the distribution of *Chenopodium hircinum* on the eastern slopes and plains of the Andes, a wild Chenopod that could be the wild ancestor of quinoa. Due to the weedy character of quinoa, it has been proposed that it co-evolved with camelid domestication (Kuznar 1993; Pearsall 1989; Smith 1998b). A second domesticate from this region is *Chenopodium pallidicaule* or *kañawa*, which has wild ancestors in the region and has received less study (Bruno 2006), though research is actually taking place on its character and domestication process (M. Bruno pers. comm. 2010). It seems that during the Formative period in the Bolivian Highlands, different varieties of chenopods were manipulated (Langlie *et al.* 2011). As domesticated specimens need to be determined by observation of different characteristics (testa thickness, seed size and morphology, testa texture) (Bruno 2001; 2006; Bruno & Whitehead 2003), these methods should be applied for all the earliest archaeological samples if we want to accurately assess the history of this crop.

Earlier specimens of quinoa have been identified in the Bolivian Highlands, dated at Chiripa as early as 3450BP (Bruno 2001; 2006; Bruno & Whitehead 2003). Langlie *et al.* (2011) describe a new archaeological morphological type of *Chenopodium* sp. at the La Barca site, located in the Department of Oruro, Bolivia by 3024±35 14C years BP cal. Also thin testa seeds come from 4950BP levels in the Peru Junin basin, Panalauca and Pancan caves (Nordstrom 1990). Eisentraut (1998) obtained a direct AMS date of 2740BP at Quelcatani cave in Peru. In the Central Chilean Highlands, Planella (2005; 2011) reports cf. *Chenopodium quinoa* as well as the possibility of an unknown variety of domestic *Chenopodium* or *Chenopodium pallidicaule* in hunter-gatherer contexts (4950-2250BP).

Based on these findings, a liberal estimate of the timing of quinoa domestication in the Andes will be 5000BP versus a conservative estimate of 3500BP (Bruno 2006). Babot (2004) reports the presence of quinoa and amaranth microfossils on tools dated between 5350-3150BP in Northwestern Argentina Puna: therefore, this date could be congruent with the liberal estimate. In the Western Atacama Puna, there are no accurate studies that allow a specific taxonomic level to be established (Belmar & Quiroz 2005; McRostie 2007; Vidal 2007). On the Chilean Coast, early Chenopods (quinoa) have been mentioned, though they are not directly dated or accurately described (Focacci 1974; Muñoz 1983; Núñez 1971;

1982; Uhle 1917). Table 8 shows some of the earliest findings of pseudocereals in South America.

Country	Area	Site/Complex	Taxa	Type	ca BP (oldest)	Reference
Peru	Highland	Ñanchoc valley	<i>Cf. Chenopodium quinoa</i>	seed	7500	Dillehay et al 2007
Chile	Coast	Chinchorro	<i>Chenopodium quinoa</i>	macro	5450	Uhle 1922
Chile	Coast	Caleta Huelen 20	<i>Chenopodium quinoa</i>	seed	5200	Núñez 1971 in Vidal 2007
Peru	Highland	Panalauca	<i>Cf. Chenopodium quinoa</i>	seed	5050	Pearsall 1989
Chile	Highland	El Plomo	<i>Cf. Chenopodium quinoa</i>	macro	5000	Planella et al 2011
Chile	Highland	Las Morrenas	<i>Cf. Chenopodium quinoa</i>	macro	5000	Planella 2005
Peru	Highland	Panalauca, Pacan	<i>Cf. Chenopodium quinoa</i>	seed	5000	Nordstrom 1990
Arg	Highland	various sites	<i>Cf. Chenopodium quinoa</i>	sg	4700	Babot 2006
Bolivia	Highland	Wankarani	<i>Cf. Chenopodium quinoa</i>	seed	4000	Langlie 2011
Bolivia	Highland	Chiripa	<i>Cf. Chenopodium quinoa</i>	seed	3500AMS	Bruno & Whitehead 2003
Arg	Puna	Peñas chicas	<i>Chenopodium quinoa</i>	macro	3500	Aguirre 2005
Chile	Highland	Tulan 54	<i>Cf. Chenopodium quinoa</i>	seed	3350	McRostie 2007
Chile	Coast	various sites	<i>Chenopodium quinoa</i>	seed	3000	in Vidal 2007
Chile	Highland/coast	various sites	<i>Chenopodium sp.</i>	seed	3000	various
Chile	Highland	Chorrillos	<i>Chenopodium sp.</i>	seed	2800	Belmar & Quiroz 2005
Chile	Coast	Faldas del Morro	<i>Chenopodium quinoa</i>	macro	2750	Dauelsberg 1985
Peru	Highland	Quelcatani	<i>Chenopodium quinoa</i>	seed	2740AMS	Eisentraut 1998
Chile	Highland	Gatchi, Calar	<i>Chenopodium sp.</i>	seed	2300	Vidal 2007
Chile	Coast	Playa Miller 7	<i>Chenopodium quinoa</i>	macro	2290	Erices 1975
Chile	Coast	Alto Ramirez	<i>Chenopodium quinoa</i>	macro	1950	Dauelsberg 1972
Chile	Coast	Azapa 6	<i>Chenopodium quinoa</i>	macro	1400	Erices 1975
Arg	Highland	Punta de la Peña 4	<i>Chenopodium quinoa</i>	seed	690AMS	Rodríguez & Aschero 2007

Table 8. Normalised dates (BP) for the appearance of High Complex pseudocereals (sg: starch grain).

The Mid elevation Complex

Similar to the Highland Complex, most of the early data for this complex come from the coastal sites of Peru. These crops are not found in the Western Atacama Puna, however in their surroundings the most ubiquitous are beans and to a lesser extent peanuts, amaranthus and coca (Table 9).

Phaseolus

Phaseolus lunatus and *Ph. vulgaris* have two areas of domestication: Central and Southern America. Both of these species of bean grow wild at elevations around 1500-2500masl from Mexico to Northwestern Argentina (Smith 1998b). In southern America, it is assumed that both were domesticated in high valleys, given the present population of wild progenitors on the eastern slopes of the Andes (Smith 1998b). Gepts (1990) determines that *Phaseolus vulgaris* was domesticated twice: in Mexico and in the southern Andes. Kaplan and Lynch (1999) suggest that *Phaseolus lunatus* was domesticated from wild populations in the South American Andes.

AMS dates on beans from the site of Chilca, on the southern coast of Peru, gave 5616-6920BP, suggesting that by 7000BP this species was already domesticated in the area (Kaplan & Lynch 1999). On the Peruvian Coast, Ugent *et al.* (1986) report beans in Pampa Rosario and Las Haldas (2760-2400BP, 2990-2845BP). In the highlands of Peru, at Guitarrero Cave (2500masl), *Ph. vulgaris* was AMS dated by 4337BP and *lunatus* around 3495BP, whilst in northern Chile the earliest dates of San Pedro Viejo de Pichasca were re-dated in 1429BP (Kaplan & Lynch 1999). In northwestern Argentina, *Phaseolus* seeds were reported in Cueva de los Corrales by 2060BP (Lema 2009). Formative sites on the northern coast of Chile (2950-1450BP) also present *Phaseolus vulgaris* and *lunatus* (Núñez 1982; 1984; Reichert 1913; Rivera *et al.* 1995-1996; Romero *et al.* 2004). Early micro-remains have been reported in the Ñanchoc valley, northern Peru, where starch grains of *Phaseolus* beans were found in teeth calculus by 8000BP (Piperno & Dillehay 2008). Also microfossils have been identified in hunter gatherer contexts of Northwestern Argentina by 6000-3500BP (Hocsman 2006; Rodríguez *et al.* 2006).

Country	Area	Site/Complex	Taxa	Type	ca BP (oldest)	Reference
Peru	Highland	Ñanchoc valley	<i>Phaseolus</i> sp.	sg	8200	Piperno & Dillehay 2008
Peru	Coast	La Paloma	<i>Phaseolus</i> sp.	macro	7650	in Pearsall 2008
Arg	Puna	QS3	<i>Phaseolus</i> sp.	sg	6000	Babot 2004
Peru	Coast	Chilca	<i>Phaseolus lunatus</i>	fruits	5616AMS	Kaplan & Lynch 1999
Arg	Highland	Huachichocana, Inca Cave, Puente del diablo, La Gruta 1	<i>Phaseolus</i> sp.	macro	4450	in Pearsall 2008
Peru	Highland	Guitarrero	<i>Phaseolus vulgaris</i>	seeds & fruits	4300AMS	Kaplan & Lynch 1999
Peru	Highland	Guitarrero	<i>Phaseolus lunatus</i>	seeds	3400AMS	Kaplan & Lynch 1999
Chile	Coast	various sites	<i>Phaseolus vulgaris/ lunatus</i>	seeds	3000	Núñez 1974, Erices 1975
Peru	Coast	Las Haldas	<i>Phaseolus</i> sp.	macro	2990	Ugent et al 1986
Peru	Coast	Pampa Rosario	<i>Phaseolus</i> sp.	macro	2760	Ugent et al 1986
Peru	Highland	Huacaloma	<i>Phaseolus vulgaris</i>	seeds	2600AMS	Kaplan & Lynch 1999
Chile	Coast	Azapa 70	<i>Phaseolus</i> sp.	?	2550	Muñoz 2004, Romero et al 2004
Peru	Highland	Huacaloma	<i>Phaseolus lunatus</i>	seeds	2400AMS	Kaplan & Lynch 1999
Chile	Coast	Playa Miller 7	<i>Phaseolus</i> sp.	macro	2297	Erices 1975
Chile	Highland	Topater	<i>Phaseolus vulgaris</i>	seeds	2150	Thomas et al 1995
Arg	Highland	Cueva los corrales	<i>Phaseolus</i> sp.	seeds	2060	Lema 2009
NOA	Highland	Cueva Los Corrales	<i>Phaseolus</i> sp.	seeds	2000	Lema 2009
Chile	Coast	Alto Ramirez	<i>Phaseolus</i> sp.	macro	1950	Dauelsberg 1972
Chile	Highland	Pichasca	<i>Phaseolus vulgaris</i>	seeds	1420AMS	Kaplan & Lynch 1999
Chile	Coast	Azapa 6	<i>Phaseolus</i> sp.	macro	1400	Erices 1975
Chile	Coast	Pircas	<i>Phaseolus lunatus</i>	?		Núñez 1984 in Vidal 2007

Table 9. Normalised dates (BP) for the appearance of Middle Complex beans (sg: starch grain).

Arachis

Arachis seems to be domesticated from crosses between wild *A. monticola* found within 1400-2800masl in Northwestern Argentina and *A. batizocoi* present from southern Bolivia to Northwestern Argentina (Pearsall 2008).

Piperno and Dillehay (2008) report the early presence of peanuts (9200-5500BP) in the Ñanchoc valley, northern Peru through examination of starch grains preserved in the calculus of human teeth and macro-remains (Dillehay *et al.* 2007). In Peruvian coast sites, peanuts have been found around 3735-2400BP (Ugent *et al.* 1986). In Argentinian Puna (5380 ± 80BP) a broken husk of *Arachis* sp. was found (Rodríguez 1999b). In Caral, on the coast of Peru, *Arachis hypogaea* is reported around 4950-3750BP (Shady 2006). In Caserones, on the northern coast of Chile, *Arachis* seeds are reported around 2350BP (Castro & Tarragó 1992; Núñez 1981b) (Table 10).

Country	Area	Site/Complex	Taxa	Type	ca BP (oldest)	Reference
Peru	Highland	Ñanchoc valley	<i>Arachis sp.</i>	sg	8000	Piperno & Dillehay 2008
Peru	Highland	Ñanchoc valley	<i>Arachis sp.</i>	hull	7840AMS	Dillehay et al 2007
Arg	Highland	Catamarca	<i>Arachis sp.</i>	husk	5300	Rodríguez 1999
Peru	Coast	Caral	<i>Arachis hypogaea</i>	hull	4000	Shady 2006
Peru	Coast	Pampa Llamas, Moxeke	<i>Arachis hypogaea</i>	macro	3735	Ugent et al 1986
Peru	Coast	Las Haldas	<i>Arachis hypogaea</i>	macro	3000	Ugent et al 1986
Peru	Coast	Pampa Rosario	<i>Arachis hypogaea</i>	macro	2760	Ugent et al 1986
Chile	Coast	Caserones	<i>Arachis sp.</i>	seeds	2350	Castro & Tarrago 1992
Chile	Coast	Caserones	<i>Arachis sp.</i>	macro	2350	Núñez 1981, 1982
Bolivia	Lowland	Llanos de Mojos	<i>Arachis hypogaea</i>	shell	1400	Dickau et al 2012
Bolivia	Lowland	Llanos de Mojos	<i>Arachis hypogaea</i>		1400	Dickau et al 2012
Bolivia	Lowland	Llanos de Mojos	<i>Arachis hypogaea</i>	sg	1400	Dickau et al 2012
Bolivia	Lowland	Llanos de Mojos	<i>Arachis hypogaea</i>	testa	1400	Dickau et al 2012

Table 10. Normalised dates (BP) for the appearance of Middle Complex *Arachis* (sg: starch grain).

Pseudocereals and tubers

Babot (2004) reports *Amaranthus caudatus* starch grains around 4100-3200BP in puna and prepuna contexts of Catamarca, Northwestern Argentina. Among the tubers of this complex, just one has been reported archaeologically (*Pachyrrhizus ahipa*) in the preceramic Peruvian Coast (Pearsall 1992, 195). Other fruits and tubers such as *Psidium guajava* and *Smallanthus sonchifolius* have been reported at coastal sites from Chile and Peru (Table 11).

Country	Area	Site/Complex	Taxa	Type	ca BP (oldest)	Reference
Peru	Coast	La Paloma	<i>Psidium guajava</i>	macro	8000	in Pearsall 2008
Peru	Coast	La Paloma	<i>Psidium guajava</i>	macro	8000	in Pearsall 2008
Peru	Coast	Chilca I	<i>Pachyrrhizus ahipa</i>	macro	6000	in Pearsall 2008
Arg	Highland	various sites	<i>Amaranthus</i> sp.	sg	4100	Babot 2006
Peru	Coast	Buena vista	<i>Psidium guajava</i>	macro	4000	Duncan et al 2009
Chile	Coast	Azapa 6	<i>Smallanthus sonchifolius</i>	macro	1400	Erices 1975

Table 11. Normalised dates (BP) for the appearance of Middle Complex pseudocereals, fruits and tubers (sg: starch grain).

Erythroxylon coca

Erythroxylon coca, the main Andean stimulant, occurs wild on the eastern Andes slopes of Ecuador, Argentina and Bolivia. Archaeologically the preservation of coca is often poor because of its fragmentary nature, the poor preservation of leaf material and the lack of rigorous archaeobotanical techniques (Hastorf 1987; Plowman 1984). There are two species as well as different varieties, *Erythroxylum coca* var. *coca* and var. *Ipadu*, which both grow on the eastern slopes of the Andes between Bolivia and Ecuador (500-2000masl) and in the western Amazon; and *Erythroxylum novogranatense*, which is adapted to the hot, moist climates of Colombia and coastal Venezuela, with the one distinct variety of *E. novogranatense* var. *truxillense* selected for the dry climates of the Peruvian coast. Today it grows along dry coastal areas of northern Peru from 200 to 1200masl (Cortella et al. 2001; Hastorf 1987; Plowman 1984). In this sense, the limited altitudinal range where coca can be grown implies an interaction when it is found in highland areas.

The dates of domestication are unknown, although indirect evidence of lime processing to release the biologically active alkaloid in the leaves suggests that coca chewing could be a practice that goes back to 7000BP in the Ñanchoc Valley (Dillehay et al. 2007) as well direct presence of leaves confirm this practice in the area (Dillehay et al. 2010). Most findings of coca leaves come from the Peruvian Coast. On the Chilean Coast, macro-botanical evidence, together with BZE analyses in hair, have provided fruitful evidence of coca consumption from 3450BP until Inca times (Cartmell et al. 1991). In Lima department findings are dated around 3700-2050BP, though the variety is not precise. Other findings from later periods

discovered in Vista Alegre in the Rimac Valley (Dept Lima), Yauca Valley (Dept Arequipa), Nazca in the Taruga Valley and Monte Grande in the Rio Grande Valley (Dept Ica), and Chacota near Arica in northernmost Chile have been undoubtedly determined as *E. coca* var. *truxillense*. These identifications were made with leaf material but also coca endocarps. In Ayacucho, Peru, during the Preceramic period 6 (6150–4450BP), MacNeish *et al.* (1975) report *E. coca* var. *coca*, though Plowman (1984) doubts it. Hastorf (1987), in the Upper Mantaro Valley, also in Peru, recovered for later periods (650–417BP) two endocarps and a coca leaf undoubtedly identified as *E. coca* var. *coca* (Cortella *et al.* 2001). Leaves of unknown variety have also been reported as an offering in Topater cemetery, northern Chile (Thomas *et al.* 1995) (Table 12).

Country	Area	Site/Complex	Taxa	Type	ca BP (oldest)	Reference
Peru	Highland	Ñanchoc	<i>Erythroxylon coca</i>	leaves	8000	Dillehay <i>et al</i> 2010
Peru	Highland	Ayacucho	<i>Erythroxylon coca</i>	leaves	6000	Mac Neish <i>et al</i> 1975
Peru	Coast	various sites	<i>Erythroxylon coca</i>	macro	4000	Cortella <i>et al</i> 2001
Chile	Coast	various sites	<i>Erythroxylon coca</i>	BZE in hair	3000	Cartmell <i>et al</i> 1991
Chile	Highland	Topater	<i>Erythroxylon coca</i>	macro	3000	Thomas <i>et al</i> 1995
Chile	Coast	Azapa 6	<i>Erythroxylon coca</i>	macro	1400	Erices 1975
Peru	Highland	Mantaro	<i>Erythroxylon coca</i>	leaves/endocarp	400	Hastorf 1987

Table 12. Normalised dates (BP) for the appearance of Middle Complex *Erythroxylon coca*.

The Low elevation Complex

Almost half of the domesticated plants from the New World are thought or known to have been domesticated in the warm and tropical lands of Central and South America (Piperno & Pearsall 1998a). This conception of the lowlands of the eastern slope of the Andes, which leads to the Amazonian basin as the major area from where crops were domesticated is shared by different scholars (Cárdenas 1969; Fernández Distel 1999; Korstanje 2005; Lathrap 1970; 1973; 1977; Parodi 1966; Sauer 1952) and they are widely reported through space and time in South America (Table 13).

Tubers

Among the lowland roots and tubers, early evidence is largely lacking (Pearsall 2008, 105) and wild ancestors are still not well defined (e.g. *Manihot esculenta*, *Calathea allouia*), though *Ipomoea batata*, *Maranta arundinacea*, *Canna edulis* and *Arracacia xanthorrhiza* seem to have a South-American origin (Hawkes 1989). *Canna edulis* has different proposals for areas of domestication, from the southern Peruvian mountains to the Colombian rainforest (Ugent *et al.* 1984). Fortunately, phytoliths and starches are giving a new cumulate of evidence (Chandler-Ezell *et al.* 2006; Dillehay *et al.* 1997; Perry *et al.* 2007; Piperno & Holst 1998). In Real Alto, Ecuador phytoliths and starches of *Calathea allouia*, *Manihot esculenta*, *Maranta arundinacea* and *Canna edulis* have been found in a time span of 4750-4350BP (Chandler-Ezell *et al.* 2006; Perry *et al.* 2007) and on the Panama Coast, microfossils of *Calathea allouia*, *Manihot esculenta*, *Maranta arundinacea* and *Canna edulis* have been reported (Piperno *et al.* 2000; Piperno *et al.* 2009). Babot (2004) found starches of *Canna edulis* attached to grinding tools in Northwestern Argentina (4100-3200BP). Perry *et al.* (2006) have recovered starches from *Maranta arundinaceae* in Huaynuma, Peruvian Highlands (4000BP). *Ipomoea batata*, *Manihot esculenta* and *Dioscorea* sp. have been reported on the Peruvian Coast around 3755-2400BP (Ugent *et al.* 1986) and around 2000BP on the northern coast of Chile (Erices 1975; Focacci 1974; Muñoz 1983). *Canna edulis* leaves have been recovered in coastal sites of Central Peru and their ubiquity led Cohen (1978) to propose that *achira* along with *cassava* were the dominant food plants during the Preceramic period. Even if the origin and time of introduction of these crops into the region is still under debate, *Manihot esculenta* was a basic food crop in the Amazonian Lowlands toward the year 3000BP (Meggers 1973) and is a main staple just like maize and potatoes (Rothhammer *et al.* 2009), producing more carbohydrates than any other lowland root/tuber (Pearsall 2008).

Country	Area	Site/Complex	Taxa	Type	ca BP (oldest)	Reference
Peru	Highland	Tres Ventanas	<i>Cf. Ipomoea batata</i>	macro	10000	Engel 1970, 1984
Ecuador	Coast	SW	<i>Calathea allouia</i>	phyto/sg	9300	in Piperno 2009
Panama	Coast	Aguadulce	<i>Manihot esculenta</i>	micro	9000	Perry et al 2007
Panama	Coast	Central	<i>Calathea allouia</i>	phyto	8000	in Piperno 2009
Panama	Coast	Central	<i>Maranta arundinacea</i>	phyto	8000	in Piperno 2009
Panama	Coast	Western/central pacific	<i>Manihot esculenta</i>	sg	7400	Dickau et al 2007
Panama	Coast	Western/central pacific	<i>Maranta arundinacea</i>	sg	7400	Dickau et al 2007
Panama	Coast	Aguadulce	<i>Dioscorea sp.</i>	sg	7000	Piperno et al 2000
Panama	Coast	Aguadulce	<i>Manihot esculenta</i>	sg	7000	Piperno et al 2000
Peru	Highland	Ñanchoc valley	<i>Manihot esculenta</i>	macro	6200AMS	Dillehay et al 2007
Peru	Coast	Chilca I	<i>Canavalia</i>	macro	5650	in Pearsall 2008
Peru	Coast	Chilca I	<i>Canna edulis</i>	macro	5650	in Pearsall 2008
Ecuador	Coast	SW	<i>Maranta arundinacea</i>	phyto/sg	5500	in Piperno 2009
Ecuador	Coast	Loma Alta	<i>Canavalia</i>	sg	5300AMS	Zarrillo et al 2008
Ecuador	Coast	Loma Alta	<i>manihot esculenta</i>	sg	5300AMS	Zarrillo et al 2008
Panama	Coast	Zapotal	<i>Dioscorea sp.</i>	micro	4800	Perry et al 2007
Panama	Coast	Zapotal	<i>Manihot esculenta</i>	micro	4800	Perry et al 2007
Ecuador	Lowland	Real Alto	<i>Achira</i>	phyto	4750	in Pearsall 2008
Ecuador	Coast	Real Alto	<i>Calathea allouia</i>	phyto	4750	Chandler ezzel et al 2006
Ecuador	Coast	Real Alto	<i>Calathea sp.</i>	sg	4750	Perry et al 2007
Ecuador	Coast	Real Alto	<i>Canna edulis</i>	sg	4750	Perry et al 2007
Ecuador	Coast	Real Alto	<i>Manihot esculenta</i>	phyto	4750	Chandler ezzel et al 2006
Ecuador	Coast	Real Alto	<i>Manihot esculenta</i>	sg	4750	Chandler ezzel et al 2006
Ecuador	Coast	Real Alto	<i>Manihot esculenta</i>	phyto	4750	in Pearsall 2008
Ecuador	Coast	Real Alto	<i>Manihot esculenta</i>	sg	4750	Perry et al 2007
Ecuador	Coast	Real Alto	<i>Maranta arundinacea</i>	phyto	4750	Chandler ezzel et al 2006
Ecuador	Coast	Real Alto	<i>Maranta arundinacea</i>	sg	4750	Chandler ezzel et al 2006
Ecuador	Coast	Real Alto	<i>Maranta arundinacea</i>	sg	4750	Perry et al 2007
Peru	Coast	Ancon-Chillon	<i>Ipomoea batata</i>	macro	4500	Martins-Farias 1976 in Hawkes 1989

Peru	Coast	Ancon-Chillon	<i>Manihot esculenta</i>	macro	4500	Martins-Farias 1976 in Hawkes 1989
Ecuador	Coast	SW	<i>Manihot esculenta</i>	phyto/sg	4300	in Piperno 2009
Peru	Coast	Buena vista	<i>Ipomoea batata</i>	rinds	4200	Duncan et al 2009
Peru	Coast	Buena vista	<i>Manihot esculenta</i>	macro	4200	Duncan et al 2009
Peru	Coast	Buena vista	<i>Manihot esculenta</i>	sg	4200	Duncan et al 2009
Peru	Coast	Buena vista	<i>Maranta arundinacea</i>	sg	4200	Duncan et al 2009
Peru	Coast	Huaca Preta	<i>Canna edulis</i>	macro	4100	Bird et al 1985
Arg	Highland	various sites	<i>Canna edulis</i>	sg	4100	Babot 2006
Peru	Coast	Huaynuma	<i>Ipomoea batata</i>	macro	4100	Ugent et al 1981
Peru	Highland	Huaynuma	<i>Maranta arundinacea</i>	sg	4000	Perry et al 2006, 2007
Peru	Coast	Pampa Llamas, Moxeke	<i>Canna edulis</i>	macro	3730	Ugent et al 1986
Peru	Coast	Pampa Llamas, Moxeke	<i>Ipomoea batata</i>	macro	3730	Ugent et al 1986
Peru	Coast	Pampa Llamas, Moxeke	<i>Manihot esculenta</i>	macro	3730	Ugent et al 1986
Chile	Coast	La Capilla 1	<i>Ipomoea batata</i>	macro	3600	Muñoz & Chacama 1982 in Rotthammer et al 2008
Chile	Coast	La Capilla 1	<i>Manihot esculenta</i>	macro	3400	Muñoz & Chacama 1982 in Rotthammer et al 2008
Chile	Coast	Azapa 71	<i>Canna edulis</i>	macro	3000	Santoro 1980 in Rotthammer et al 2008
Chile	Coast	Azapa 71	<i>Manihot esculenta</i>	macro	3000	Santoro 1980 in Rotthammer et al 2008
Peru	Coast	Las Haldas	<i>Manihot esculenta</i>	macro	3000	Ugent et al 1986
Peru	Coast	Pampa Rosario	<i>Canna edulis</i>	macro	2760	Ugent et al 1986
Chile	Coast	Azapa 12	<i>Ipomoea batata</i>	macro	2500	Muñoz 1986 in Rotthammer et al 2008
Chile	Coast	PML 7	<i>Canna edulis</i>	macro	2480	Erices 1975 en Rotthammer et al 2009
Chile	Coast	PML 7	<i>Ipomoea batata</i>	macro	2480	Erices 1975 en Rotthammer et al 2009
Chile	Coast	PML 7	<i>Manihot esculenta</i>	macro	2480	Focacci 1974 in Rotthammer et al 2009

Chile	Coast	Azapa 14	<i>Ipomoea batata</i>	macro	2300	Santoro 1980 in Rotthammer et al 2008
Chile	Coast	Azapa 70	<i>Ipomoea batata</i>	macro	2300	Muñoz 2004, Romero et al 2004
Chile	Coast	Azapa 14	<i>Manihot esculenta</i>	macro	2300	Santoro 1980 in Rotthammer et al 2008
Chile	Coast	Azapa 70	<i>manihot esculenta</i>	macro	2300	Muñoz 2004, Romero et al 2004
Chile	Coast	Playa Miller 7	<i>Canna edulis</i>	macro	2000	Erices 1975
Chile	Coast	Playa Miller 7	<i>Ipomoea batata</i>	macro	2000	Erices 1975
Chile	Coast	Playa Miller 7	<i>Manihot esculenta</i>	macro	2000	Erices 1975
Chile	Coast	Alto Ramirez	<i>Ipomoea batata</i>	macro	1950	Dauelsberg 1972
Chile	Coast	Azapa 6	<i>Ipomoea batata</i>	macro	1400	Erices 1975
Chile	Coast	Azapa 6	<i>Manihot esculenta</i>	macro	1400	Erices 1975
Bolivia	Lowland	Llanos de Mojos	<i>Manihot esculenta</i>	sg	1400	Dickau et al 2012

Table 13. Normalised dates (BP) for the appearance of Low Complex tubers (sg: starch grain, phyto: phytolith).

Capsicum

Different lines of evidence suggest that in South America, three species were domesticated: *C. baccatum* in lowland Bolivia, *C. chinense* in northern lowland Amazonia and *C. pubescens* in the mid-elevation southern Andes (Perry *et al.* 2007). This genus has been reported in different countries and areas through time (Table 14). Early starch of the *Capsicum* genus has been found in Waynuna, a Late Preceramic house (4000-1000BP) at 3600masl in the Peruvian Andes (Perry *et al.* 2007). In Huachichocana and other caves in the highlands of Northwestern Argentina, this genus has been reported by 4450-2450BP (Pearsall 2008). *Capsicum* has also been reported in northern Chile during the Formative period (Holden 1991; Muñoz 1983; Santoro 1980). But in Western Atacama Puna, a single seed of cf. *Capsicum* pepper was very small for a cultivated variety (Holden 1991). Several early dates in Peruvian caves have recently been shown to be later (Kaplan & Lynch 1999). It seems that in pre-ceramic periods, these species were used as condiments and ritual occasions rather than as staple foods (Hastorf 1999; Perry *et al.* 2007).

Country	Area	Site/Complex	Taxa	Type	ca BP (oldest)	Reference
Ecuador	Coast	Loma Alta	<i>Capsicum sp.</i>	sg	6000	Perry et al 2007
Panama	Coast	Aguadulce	<i>Capsicum sp.</i>	sg	5600	Perry et al 2007
Ecuador	Coast	Loma Alta	<i>Capsicum sp.</i>	sg	5300AMS	Zarrillo et al 2008
Panama	Coast	Zapotal	<i>Capsicum sp.</i>	sg	4800	Perry et al 2007
Panama	Coast	Zapotal	<i>Capsicum sp.</i>	micro	4800	Perry et al 2007
Arg	Highland	Huachichocana, Inca Cave, Puente del diablo, La Gruta 1	<i>Capsicum sp.</i>	macro	4450	in Pearsall 2008
Ecuador	Coast	Real Alto	<i>Capsicum sp.</i>	sg	4400	Perry et al 2007
Peru	Coast	Buena vista	<i>Capsicum sp.</i>	seed	4150	Duncan et al 2009
Peru	Coast	Buena vista	<i>Capsicum sp.</i>	sg	4150	Duncan et al 2009
Peru	Coast	Huaca Preta	<i>Capsicum baccatum</i>	fruits	4000	Perry et al 2007
Peru	Coast	Huaca Preta	<i>Capsicum baccatum</i>	fruits	4000	Perry et al 2007
Peru	Coast	Huaca Preta	<i>Capsicum baccatum</i>	fruits	4000	Perry et al 2007
Peru	Coast	Huaca Preta	<i>Capsicum chinense</i>	fruits	4000	Perry et al 2007
Ecuador	Coast	Loma Alta	<i>Capsicum sp.</i>	sg	4000	Perry et al 2007
Peru	Highland	Huaynuma	<i>Capsicum sp.</i>	sg	3900	Perry et al 2006, 2007
Peru	Coast	Casma	<i>Capsicum chinense</i>	fruits	3500	Perry et al 2007 in
Peru	Coast	Casma	<i>Capsicum chinense</i>	fruits	3500	Perry et al 2007
Peru	Highland	Huaynuma	<i>Capsicum sp.</i>	sg	3500	Perry et al 2006, 2007
Peru	Coast	Las Haldas	<i>Capsicum sp.</i>	macro	3000	Ugent et al 1986
Chile	Coast	various sites	<i>Capsicum sp.</i>	macro	3000	in Vidal 2007
Peru	Coast	Pampa Rosario	<i>Capsicum sp.</i>	macro	2750	Ugent et al 1986
Chile	Coast	Azapa 70	<i>Capsicum sp.</i>	macro	2500	Muñoz 2004, Romero et al 2004
Chile	Highland	Tulan 58	<i>Capsicum sp.</i>	macro	2240	Holden 1991
Chile	Coast	Playa Miller 7	<i>Capsicum sp.</i>	macro	2100	Erices 1975

Table 14. Normalised dates (BP) for the appearance of Low Complex *Capsicum* (sg: starch grain).

Gossypium

Gossypium barbadense is a premier industrial plant from which textiles, ropes, and other crafts are made. This species seems to have been domesticated in the North-western South American Andes (Pearsall 2008). The earliest evidence has been found in Real Alto, Ecuador (5450-4950BP) (Damp & Pearsall 1994) and from the Ñanchoc valley in Peru (5490BP)

(Dillehay *et al.* 2007). For the Pre-ceramic Cotton period in coastal Peru, evidence of cotton is present from at least 4450BP (Stephens & Moseley 1973; Ugent *et al.* 1986). On the Chilean Coast, *Gossypium barbadense* has been reported for several Formative sites (2950-950BP) (Dauelesberg 1985; Erices 1975; Muñoz 1983; 2004; Núñez 1969; Romero *et al.* 2004; Uhle 1917); whilst in the highlands sites of Western Atacama Puna, this species is reported only in two early Formative sites, Chiu Chiu 200 and Tulan 109 (Benavente 1978; 1988-1989; Núñez *et al.* 2006) (Table 15).

Complex	Country	Area	Site/Complex	Taxa	Type	ca BP (oldest)	Reference
Low	Chile	Coast	Quiani	<i>Gossypium</i> sp.	macro	6000	Dauelsberg 1972
Low	Ecuador	Coast	Real Alto	<i>Gossypium barbadense</i>	seeds	5450	Damp & Pearsall 1994
Low	Ecuador	Coast	Real Alto	<i>Gossypium</i> sp.	seeds	5450	Damp & Pearsall 1994
Low	Peru	Highland	Ñanchoc valley	<i>Gossypium barbadense</i>	fiber	5400AMS	Dillehay et al 2007
Low	Peru	Coast	Ancon-Chillon	<i>Gossypium</i> sp.	macro	4450	Stephen & Moseley 1974
Low	Peru	Coast	Buena vista	<i>Gossypium barbadense</i>	macro	4200	Duncan et al 2009
Low	Peru	Coast	El Paraiso	<i>Gossypium</i> sp.	seeds	3750	Damp & Pearsall 1994
Low	Peru	Coast	Pampa Llamas, Moxeke	<i>Gossypium barbadense</i>	macro	3650	Ugent et al 1986
Low	Peru	Coast	Las Haldas	<i>Gossypium barbadense</i>	macro	3000	Ugent et al 1986
Low	Chile	Coast	various sites	<i>Gossypium</i> sp.	macro	3000	in Vidal 2007
Low	Chile	Highland	Chiu Chiu 200	<i>Gossypium</i> sp.	fiber	3000	Benavente 1988-89
Low	Chile	Highland	Tulan 109, Chiu Chiu 200	<i>Gossypium</i> sp.	macro	3000	Benavente 1978, 1988-89; Núñez et al 2006
Low	Chile	Coast	fase canamo monticulo	<i>Gossypium</i> sp.	macro	2800	Núñez & Moraga 1983
Low	Peru	Coast	Pampa Rosario	<i>Gossypium barbadense</i>	macro	2760	Ugent et al 1986
Low	Chile	Coast	Playa Miller 7	<i>Gossypium</i> sp.	macro	2250	Erices 1975
Low	Chile	Coast	Azapa 6	<i>Gossypium</i> sp.	macro	1450	Erices 1975
Low	Chile	Coast	Azapa 70	<i>Gossypium</i> sp.		1350	Muñoz 2004, Romero et al 2004

Table 15. Normalised dates (BP) for the appearance of Low Complex *Gossypium*.

Cucurbita

The *Cucurbita* genus is composed of three species, *moschata*, *maxima* and *filicifolia*, derived from different ancestral species. *Moschata* is the Lowland Tropical Forest squash, *maxima* is cultivated throughout the western Andean slopes and *filicifolia* is a high altitude, cool tolerant species that ranges from Mexico to Bolivia (Pearsall 2008, 108). Probably in the beginning these were used for their oily seeds and as containers due to their bitter flesh.

These species have not been identified during early periods on the Western Atacama Puna, even if they are part of the basic New World crop assemblage (Pickersgill 1989; Staller 2010) and have a wide distribution and range of domestication in the Americas (Lema 2009; Pearsall 1992; 2008; Piperno & Pearsall 1998a; Smith 1998b; Vavilov 1992 [1940]). The beginnings of plant husbandry appear to have been preceded by the exploitation of wild species of *Cucurbita* during the terminal Pleistocene (Piperno & Stothert 2003).

Cucurbita phytoliths have been directly dated to 10130 to 9320BP in south-western Ecuador. Their size allows to propose that they were already domesticated because they are considerably larger than those from modern wild taxa. These data provide evidence for an independent emergence of plant food production in lowland South America that was contemporaneous with or slightly before that in highland Mesoamerica (Piperno & Stothert 2003). In Central Panama, Piperno (2009) reports *Cucurbita moschata* phytoliths by 8000BP and this same species has been reported from starch in teeth calculus in the Anchoc Valley in northern Peru between 9200 and 5500BP (Piperno & Dillehay 2008). Also *Cucurbita moschata* seeds are reported by 9214-7660BP AMS dated in the Ñanchoc valley (Dillehay *et al.* 2007). Chevalier (2002) reports the presence of this genus since the Late Pleistocene on the coast and sierra of Peru. In Quebrada Los Burros, on the southern coast of Peru, *Cucurbita máxima* phytoliths were identified, being the oldest ones in South America (Chevalier 2008). Whitaker (1983) states that *Cucurbita* was cultivated in coastal Peru by 5950-4950BP years ago. Duncan *et al.* (2009) report starch grains included in rinds of *Cucurbita* and *Lagenaria* at the Buena Vista site in coastal Peru around 4150BP. In the Peruvian Highlands, Smith (1980) reports *Cucurbita* sp. by 2450-1450BP and MacNeish *et al.* (1975) report *Cucurbita* sp. in the Chihua and Cachi complex (6150-5050BP). Due to the scant presence of these species in the highlands, it seems that either this was not a proper environment to grow them or they were not a preferred crop by their inhabitants (Whitaker 1983). However, this argument does not apply to the Northwestern Argentinian Highlands, where several caves have been reported to present this genus by 4450-2450BP (Pearsall 2008), as in Cueva los Corrales 2060BP (Lema 2009). Babot (2004) found *Cucurbita* starch attached to grinding stones in sites from Northwestern Argentina by 5350-3150BP. *Cucurbita maxima* was intensively cultivated in Pampa Grande (Salta) 1500 years prior to

the Spaniards' arrival to the area, though it is thought that this pattern would have existed since pre-ceramic periods (Whitaker 1983). In Chile, this genus has been identified at various Formative coastal sites (Castro & Tarragó 1992; Núñez 1982; Santoro 1980) though it is more likely that they are rinds of *Lagenaria* sp. (Vidal 2007) (Table 16).

Country	Area	Site/Complex	Taxa	Type	ca BP (oldest)	Reference
Peru	Highland	Guitarrero	<i>Cucurbita</i> sp.	phyto	11270	Chevalier 2002 in Lema 2009
Ecuador	Coast	SW	<i>Cucurbita ecuadorensis</i>	phyto	10000	in Piperno 2009
Ecuador	Coast	Las Vegas	<i>Cucurbita</i> sp.	phyto	10000	Piperno et al 2003, 2008, Stothert et al 2003
Ecuador	Coast	Real Alto	<i>Cucurbita</i> sp.	sg	10000	Perry et al 2007
Peru	Highland	Ñanchoc valley	<i>Cucurbita moschata</i>	seed	9200AMS	Dillehay et al 2007
Colombia	Lowland	Peña Roja	<i>Cucurbita</i> sp.	phyto	9000	Gnecco & Mora 1997, Piperno & Pearsall 1998
Peru	Coast	La Paloma	<i>Cucurbita ficifolia</i>	?	8630	Chevalier 2002 in Lema 2009
Peru	Coast	La Paloma	<i>Cucurbita</i> sp.	?	8630	Chevalier 2002 in Lema 2009
Peru	Highland	Ñanchoc valley	<i>Cucurbita moschata</i>	sg	8210	Piperno & Dillehay 2008
Panama	Coast	Central	<i>Cucurbita moschata</i>	phyto	8000	in Piperno 2009
Peru	Coast	La Paloma	<i>Cucurbita</i> sp.	macro	7650	in Pearsall 2008
Ecuador	Coast	SW	<i>Cucurbita moschata</i>	phyto	7000	in Piperno 2009
Peru	Coast	Pampa	<i>Cucurbita ficifolia</i>	macro	6150	Lanning 1967 in Pearsall 1992
Peru	Coast	Pampa	<i>Cucurbita maxima</i>	macro	6150	Lanning 1967 in Pearsall 1992
Peru	Highland	Chihua	<i>Cucurbita</i> sp.	macro	6150	Macneish 1975 in Whitaker 1983
Peru	Coast	Chilca 1	<i>Cucurbita</i> sp.	?	5730	Chevalier 2002 in Lema 2009
Peru	Coast	Huaca Preta	<i>Cucurbita maxima</i>	?	5350	Chevalier 2002 in Lema 2009
Peru	Highland	Cachi	<i>Cucurbita</i> sp.	macro	5350	Macneish 1975 in Whitaker 1983
Peru	Coast	Pampa de Ventanilla	<i>Cucurbita ficifolia</i>	?	5250	Chevalier 2002 in Lema 2009
Peru	Coast	Huaca Preta	<i>Cucurbita ficifolia</i>	macro	5000	Cutler &

						Whitaker 1961
Peru	Coast	Huaca Preta	<i>Cucurbita moschata</i>	macro	5000	Cutler & Whitaker 1961
Peru	Coast	Los Gavilanes	<i>Cucurbita moschata</i>	?	5000	Chevalier 2002 in Lema 2009
Peru	Coast	Cerro lampay	<i>cucurbita pepo</i>	?	4950	Vega Centeno 2005 in Lema 2009
Peru	Coast	La Galgada	<i>Cucurbita maxima</i>	?	4820	Chevalier 2002 in Lema 2009
Peru	Coast	La Galgada	<i>Cucurbita moschata</i>	?	4820	Chevalier 2002 in Lema 2009
Peru	Coast	Huaca Preta	<i>Cucurbita ficifolia</i>	macro	4700	Whitaker 1983
Peru	Coast	Huaca Preta	<i>Cucurbita moschata</i>	macro	4700	Whitaker 1983
Arg	Highland	various sites	<i>Cucurbita sp.</i>	sg	4700	Babot 2006
Ecuador	Lowland	Las Vegas	<i>Cucurbita sp.</i>	phyto	4700	in Pearsall 2008
Peru	Coast	Caral	<i>Cucurbita sp.</i>	?	4450	Vega Centeno 2005 in Lema 2009
Arg	Highland	Huachichocana, Inca Cave, Puente del diablo, La Gruta 1	<i>Cucurbita sp.</i>	macro	4450	in Pearsall 2008
Peru	Coast	El Paraiso	<i>Cucurbita ficifolia</i>	?	4350	Chevalier 2002 in Lema 2009
Peru	Coast	El Paraiso	<i>Cucurbita maxima</i>	?	4350	Chevalier 2002 in Lema 2009
Peru	Coast	El Paraiso	<i>Cucurbita moschata</i>	?	4350	Chevalier 2002 in Lema 2009
Peru	Coast	Buena vista	<i>Cucurbita ficifolia</i>	macro	4150	Duncan et al 2009
Peru	Coast	Buena vista	<i>Cucurbita maxima</i>	macro	4150	Duncan et al 2009
Peru	Coast	Buena vista	<i>Cucurbita moschata</i>	macro	4150	Duncan et al 2009
Peru	Coast	Buena vista	<i>Cucurbita sp.</i>	sg	4150	Duncan et al 2009
Peru	Coast	Huaynuma	<i>Cucurbita ficifolia</i>	macro	4000	Whitaker 1983
Peru	Coast	Huaynuma	<i>Cucurbita maxima</i>	macro	4000	Whitaker 1983
Peru	Coast	Las Haldas	<i>Cucurbita maxima</i>	macro	4000	Whitaker 1983
Peru	Coast	Pampa llamas, Tortugas	<i>Cucurbita ficifolia</i>	macro	3750	Whitaker 1983
Peru	Coast	Pampa llamas, Tortugas	<i>Cucurbita maxima</i>	macro	3750	Whitaker 1983
Peru	Coast	Pampa Llamas, Moxeke	<i>Cucurbitacea</i>	macro	3730	Ugent et al 1986
Chile	Coast	La Capilla, Quiani	<i>Cucurbita sp.</i>	macro	3700	Castro & Tarrago 1992

Chile	Coast	Azapa 14	<i>Cucurbita sp.</i>	macro	3600	Santoro 1980
Peru	Coast	Las Haldas	<i>Cucurbitacea</i>	macro	3000	Ugent et al 1986
Peru	Coast	Pampa Rosario	<i>Cucurbitacea</i>	macro	2760	Ugent et al 1986
Peru	Coast	San Diego	<i>Cucurbita maxima</i>	macro	2500	Whitaker 1983
Peru	Coast	San Diego	<i>Cucurbita moschata</i>	macro	2500	Whitaker 1983
Peru	Highland	Guitarrero	<i>Cucurbita sp.</i>	macro	2450	Smith 1980
Chile	Coast	Tarapaca 40	<i>Cucurbita maxima</i>	macro	1650	Núñez 1982
Chile	Coast	Tarapaca 40	<i>Cucurbita moschata</i>	macro	1650	Núñez 1982
Arg	Highland	Pampa Grande	<i>Cucurbita maxima</i>	macro	1400	Whitaker 1983

Table 16. Normalised dates (BP) for the appearance of Low Complex *Cucurbita* (sg: starch grain, phyto: phytolith).

Non-indigenous pre-Columbian plants

Even if there were not originally domesticated in South America and not even in America, *Zea mays* and *Lagenaria sp.* have played a major role for the pre-Columbian population of the area.

Lagenaria

This is one of the earliest crops, though it is the only crop that originated in the Old World but appeared in the New World before Columbus arrived (Vavilov 1992 [1940]). This crop was not domesticated in America, and is native to Africa (Heiser 1985; 1989). Archaeological specimens of bottle gourd are the most common, occurring in contexts prior to 6950BP within South America (Pearsall 1992; 2008). Erickson *et al.* (2005), based on analyses of fruit rind thickness, indicate that the bottle gourd was present in America by 10000BP and that its ancestors were more closely related to Asian landraces. Although the oily seeds of *Lagenaria* were probably consumed, it is the utilitarian role of *Lagenaria* as a container, especially during pre-pottery times, which might have influenced the fact that Palaeoindian populations carried this crop during Pleistocene migrations (Erickson *et al.* 2005). These authors dated AMS radiocarbon bottle gourd rinds from sites in Peru, Mexico and eastern North America, finding all of them to have dates before 7000BP. On the northern coast of Peru, Quebrada Jaguay presented specimens dated to 8400BP and several sites confirmed

its early presence (Berman & Pearsall 2008). This early presence of bottle gourd in the Americas is also confirmed in Western Atacama Puna, where it is the first domesticate plant in the archaeological record during the Late Archaic period (McRostie 2007; Núñez 1974). In North Western Argentina it is found as microfossil in pre-ceramic times in Punta de la Peña 4 (4060-3820BP) (Babot 2004) and rinds have been found in Inca Cueva by 4080BP (Tarragó 1980), and in Huachichocana, Puente del Diablo and La Gruta 1 by 4450-1450BP (Pearsall 2008). During the Formative period, it is present in different sites of Western Atacama Puna as Tulan 54, 122, 85 by 3350-1450BP (Lema 2009; McRostie 2007), in Vega Alta II by 2450-2150BP (Pollard 1971), and appears in various sites on the northern Chilean Coast after 2450BP (Dauelsberg 1985; Muñoz 1983; 2004; Muñoz *et al.* 1991; Núñez 1974; Núñez & Moragas 1977) (Table 17).

Country	Area	Site/Complex	Taxa	Type	ca BP (oldest)	Reference
Ecuador	Coast	SW	<i>Lagenaria siceraria</i>	phyto	9300	in Piperno 2009
Ecuador	Coast	Site 80	<i>Lagenaria siceraria</i>	phyto	9000	Piperno 1988a, 1988, Piperno & Pearsall 1998
Colombia	Lowland	Peña Roja	<i>Lagenaria siceraria</i>	phyto	9000	Gnecco & Mora 1997, Piperno & Pearsall 1998
Panama	Coast	Aguadulce	<i>Lagenaria sp.</i>	micro	9000	Perry et al 2007
Peru	Coast	Siches	<i>Lagenaria siceraria</i>	macro	8000	in Pearsall 2008
Panama	Coast	Central	<i>Lagenaria siceraria</i>	phyto	8000	in Piperno 2009
Peru	Coast	La Paloma	<i>Lagenaria siceraria</i>	macro	7650	in Pearsall 2008
Arg	Highland	various sites	cf. <i>Lagenaria sp.</i>	sg	6500	Babot 2006
Chile	Coast	Quiani	<i>Lagenaria sp.</i>	macro	6000	Dauelsberg 1972
Peru	Coast	Huaca Preta	<i>Lagenaria siceraria</i>	macro	5000	Cutler & Whitaker 1961
Chile	Highland	Tulan 55	<i>Lagenaria sp.</i>	seeds, rinds	5000	Núñez et al 2006
Arg	Highland	Huachichocana, Inca Cave, Puente del diablo, La Gruta 1	<i>Lagenaria sp.</i>	macro	4450	in Pearsall 2008
Peru	Coast	Buena vista	<i>Lagenaria siceraria</i>	sg	4000	Duncan et al 2009
Chile	Highland	Tulan 52	<i>Lagenaria sp.</i>	rinds	4000	McRostie 2007
Chile	Coast	Quiani	<i>Lagenaria sp.</i>	macro	3550	Dauelsberg 1974
Chile	Highland	Tulan 54	<i>Lagenaria sp.</i>	rinds	3350	McRostie 2007
Chile	Highland	Chiu Chiu 200	<i>Lagenaria sp.</i>	rinds	3000	Benavente 1988-89
Chile	Highland	Tulan 85	<i>Lagenaria sp.</i>	seeds, rinds	2660	Núñez et al 2006
Chile	Coast	Azapa 70	<i>lagenaria sp.</i>	rinds	2500	Muñoz 2004, Romero et al 2004
Chile	Highland	Tulan 57, 59, 71, 82	<i>Lagenaria sp.</i>	rinds	2350	Núñez 2005
Chile	Highland	Gatchi, Calar	<i>Lagenaria sp.</i>	rinds	2250	Vidal 2007
Chile	Highland	Tulor 1	<i>Lagenaria sp.</i>	rinds	2250	Llagostera 1984, Baron 1986
Chile	Highland	Toconao	<i>Lagenaria sp.</i>	rinds	2200	Tarrago 1989
Chile	Coast	Playa Miller 7	<i>Lagenaria sp.</i>	macro	2100	Erices 1975
Chile	Highland	Ranl 100	<i>Lagenaria sp.</i>	rinds	1800	Pollard 1971
Chile	Coast	Azapa 6	<i>Lagenaria sp.</i>	macro	1400	Erices 1975

Table 17. Normalised dates (BP) for the appearance of non-indigenous pre-Columbian plants *Lagenaria* (sg: starch grain, phyto: phytolith).

Zea mays

Phylogenetic, morphological and taxonomical studies have concluded that maize is derived from *Teosinte parviflora*, a wild grass whose natural distribution is Mexico and Central America. The earliest macro remains have been found in a few Archaic sites in Mesoamerica (Tehuacan, Tamaulipas and Oaxaca) (Blake 2006; Smith 2001a; Staller 2010). Recent direct (AMS) dates in Guila Naguitz cave (Oaxaca) show that the oldest cobs in America have 5400BP (Piperno & Flannery 2001). However, despite the recent advances, there is still controversy as to the timing and the area of domestication. Some authors defend an “early” domestication around 10000–7000BP (Piperno & Pearsall 1998a) whilst others are more inclined towards a “late” domestication around 6000–5000BP (Fritz 1994; Smith 1998b). Also there is no consensus regarding the particular area where teosinte was initially manipulated (Benz 2001; Doebley 1990; Hastorf 2009; MacNeish & Eubanks 2000; Piperno & Flannery 2001) or the timing of its spread to southern America.

An early scenario is proposed by Piperno and Pearsall (1998a). Based exclusively on microfossil remains, they argue that maize was already present in South America around 8000-7000BP. Early pollen has been documented In Colombia Hacienda El Dorado by 6680BP (Bray *et al.* 1987) and at Hacienda Lusitania by 5150BP (Monsalve 1985). In Ecuador, the pollen from lake cores is 1000 to 2000 years more recent: Lake Ayauchi 4570BP (Bush *et al.* 1989) and Lake San Pablo 4000BP (Pearsall 1999). Regarding phytoliths, Ecuador presents early dates for Lake Ayauchi 4570BP (Bush *et al.* 1989), Las Vegas site 7150BP (Pearsall & Piperno 1990; Stothert 1985), Real Alto 4450BP (Pearsall & Piperno 1990), Loma Alta 5000BP (Pearsall 2003), La Emerenciana 3775BP (Staller & Thompson 2002) and Cotocollao 3500BP (Pearsall 2003). In addition to these samples, Staller and Thompson (2002) report an AMS date on residues from a cooking vessel that contained maize phytoliths embedded in the residues dated around 3860BP in la Emerenciana, southern Ecuador. Other microfossils such as starch grains have been recovered from stone tools (3600-4000BP) in the southern Peruvian Andes (Perry *et al.* 2006), Northwestern Argentina (3400-2700BP) (Babot 2004) and the Bolivian Highlands at Chiripa (2850-2350BP) (Logan 2006).

The fact that micro-remains findings are mainly present in tropical and subtropical environments led Pearsall (2008) to propose that the initial corridor of maize cultivation was in tune with the subtropical climate for which maize was pre-adapted and that from Northern South America, it was spread into Argentina and southern latitudes through the eastern slope on the Andes. Rivera (2006, 411) argues that the possible spread of maize may be derived from the Tropical Lowlands, based on the similarity of races like *Piricinco Coroico* in quite different environments, from the Pacific Coast to the Tropical Forest. Later it adapted to rainfall cultivation in dry coasts and high altitudes (Pearsall 2008). Lia *et al.* (2007), based on morphological, cytogenetic and genetic evidence, defend an independent maize Andean complex whose gene pool has predominated in the western regions of southern South America for at least the last 1400 years (Lia *et al.* 2007, 553). The sampling of nine specimens from Northwestern Argentina gave DNA sequences consistent with the Andean Complex. The lack of a lowland gene population supports a highland origin for maize cultivation in this region and confirms the hypotheses of two separate expansions of maize cultivation into South America, one through the highlands and the other through the lowlands (McClintock 1981 and Freitas *et al.* 2003, cited in Lia *et al.* 2007). Therefore the genetic pool of Andean maize will also characterise the northern Chile Highlands and its antiquity will not be later than that of the Lowland Complex as proposed (Matsuoka *et al.* 2002).

The lack of macro-remains in the earlier periods has been attributed to taphonomical variables that potentially can affect macro-remains' conservation but allow micro-remains to be preserved (Pearsall 2007). However, the difficulty with micro-remains is that their contexts could be disturbed due to bioturbation: therefore, where microbotanical remains such as phytoliths and pollen provide the only evidence of maize use, the timing of maize's introduction into a region is still in debate (Bruhns 1994; Fritz 1994; Pearsall 2009; Piperno & Fritz 1994; Piperno & Pearsall 1998a; Smith 1998b; Staller 2010). Also the reliability of maize phytoliths has been strongly criticised (Rovner 2004; Staller 2003; Staller & Thompson 2002).

The second or late scenario is based on carbonised cobs and kernels which have much later dates than micro-remains (Fritz 1994; Smith 1998b). On one hand, a revaluation of early

macro specimens in South America by using AMS dates has shown that dating maize by context association is unreliable (Blake 2006); therefore, AMS dating has shown older dates than initially reported (e.g. Rivera 2006). Accepted direct dates in macro remains are now available in Honduras (2280 \pm 40BP), coastal Ecuador (<3500BP), Central Argentina (2065 \pm 40BP), Chilean North coast in Tiliviche 1-b (920 \pm 32BP), Guatacondo (1865BP), Ramaditas (2210 \pm 55BP) and Pichasca (1025BP) (Blake 2006). In the Western Atacama Puna, cobs have been associated to samples dated to 2910 and 2710BP (Benavente 1988-1989; Núñez *et al.* 2006). In Central Chile, the earliest macro-remain findings date from around 1450BP (Falabella *et al.* 2007; Planella & Tagle 2004). In Peru in Pancan site (3400masl) small kernel popcorn was dated to 1500BP (Smith 1998b). In northwestern Argentina, Rodríguez and Aschero (2007) recovered different varieties of maize from Punta de la Peña 4 and 9, located in Catamarca Puna, with dates around 1970 to 530BP. They propose an intensive use of plants by hunter-gatherers, which in the next stage will develop into a horticulture and herding economy. In Campo del Pucara, Catamarca, several remains of *Zea mays var. gracillima* were dated to around 1800 and 1500BP (Oliszewski 2004). Also in the Rincon Chico site, remains were dated to 1175BP. Previous excavations reported some of the earliest maize remains in South America in the Huachichocana cave (9620-8220BP), though direct radiocarbon dates for these remains are not available yet (Rodríguez & Aschero 2007) (Table 18).

It seems that maize does not become a major staple until 3000 years ago and in many regions, such as the Andean one, not until much later towards the end of the Early Formative period (ca.1350BP) (Babot 2004; Fernández & Panarello 1988-1990; Korstanje 2005; Olivera & Yacobaccio 1999; Pearsall 1992; Rivera 2006; Tykot & Staller 2002). For instance, based on stable isotopes, Olivera & Yacobaccio (1999) concluded that maize consumption in Northwestern Argentina appears in the people's diet rather late (1200 and 600BP), associated with increasing complexity. Aufderheide *et al.* (1994), by using C¹³ stable isotopes, quantify the value of maize in the Alto Ramirez diet on the basis of the site AZ-75. Their main conclusion is that maize represented a maximum of 15.5% of total protein in that diet.

<i>Country</i>	<i>Area</i>	<i>Site/Complex</i>	<i>Taxa</i>	<i>Type</i>	<i>ca BP (oldest)</i>	<i>Reference</i>
<i>Panama</i>	<i>Coast</i>	<i>Aguadulce</i>	<i>Zea mays</i>	<i>micro</i>	<i>9000</i>	<i>Perry et al 2007</i>
<i>Colombia</i>	<i>Sierra</i>	<i>Peña Negra</i>	<i>Zea mays</i>	<i>pollen</i>	<i>8270</i>	<i>in Pearsall 2008</i>
<i>Panama</i>	<i>Coast</i>	<i>Western/central pacific</i>	<i>Zea mays</i>	<i>sg</i>	<i>7400</i>	<i>Dickau et al 2007</i>
<i>Panama</i>	<i>Coast</i>	<i>Aguadulce</i>	<i>Zea mays</i>	<i>sg</i>	<i>7000</i>	<i>Piperno et al 2000</i>
<i>Panama</i>	<i>Coast</i>	<i>Central</i>	<i>Zea mays</i>	<i>phyto/sg</i>	<i>7000</i>	<i>in Piperno 2009</i>
<i>Ecuador</i>	<i>Lowland</i>	<i>Las Vegas</i>	<i>Zea mays</i>	<i>phyto</i>	<i>7000</i>	<i>in Pearsall 2008</i>
<i>Colombia</i>	<i>Sierra</i>	<i>El Dorado</i>	<i>Zea mays</i>	<i>pollen</i>	<i>6630</i>	<i>in Pearsall 2008</i>
<i>Ecuador</i>	<i>Coast</i>	<i>Site 80</i>	<i>Zea mays</i>	<i>phyto</i>	<i>6600</i>	<i>Piperno & Pearsall 1998</i>
<i>Ecuador</i>	<i>Coast</i>	<i>SW</i>	<i>Zea mays</i>	<i>phyto</i>	<i>6600</i>	<i>in Piperno 2009</i>
<i>Ecuador</i>	<i>Coast</i>	<i>SW</i>	<i>Zea mays</i>	<i>phyto</i>	<i>6600</i>	<i>in Piperno 2009</i>
<i>Ecuador</i>	<i>Coast</i>	<i>Loma Alta</i>	<i>Zea mays</i>	<i>sg</i>	<i>6250AMS</i>	<i>Zarrillo et al 2008</i>
<i>Chile</i>	<i>Coast</i>	<i>Quiani</i>	<i>Zea mays</i>	<i>macro</i>	<i>5550</i>	<i>Dauelsberg 1972</i>
<i>Ecuador</i>	<i>Coast</i>	<i>Real Alto</i>	<i>Zea mays</i>	<i>phyto</i>	<i>5450</i>	<i>in Pearsall 2008</i>
<i>Colombia</i>	<i>Sierra</i>	<i>Lusitania</i>	<i>Zea mays</i>	<i>pollen</i>	<i>5100</i>	<i>in Pearsall 2008</i>
<i>Ecuador</i>	<i>Lowland</i>	<i>Loma Alta</i>	<i>Zea mays</i>	<i>phyto</i>	<i>5000</i>	<i>in Pearsall 2008</i>
<i>Ecuador</i>	<i>Coast</i>	<i>Real Alto</i>	<i>Zea mays</i>	<i>sg</i>	<i>4800</i>	<i>Chandler ezzel et al 2006</i>
<i>Panama</i>	<i>Coast</i>	<i>Zapotal</i>	<i>Zea mays</i>	<i>micro</i>	<i>4800</i>	<i>Perry et al 2007</i>
<i>Ecuador</i>	<i>Coast</i>	<i>Real Alto</i>	<i>Zea mays</i>	<i>phyto</i>	<i>4750</i>	<i>in Pearsall 2008</i>
<i>Ecuador</i>	<i>Coast</i>	<i>Real Alto</i>	<i>Zea mays</i>	<i>sg</i>	<i>4700</i>	<i>Perry et al 2007</i>
<i>Arg</i>	<i>Highland</i>	<i>Inca Cave, Puente del diablo, La Gruta 1</i>	<i>Zea mays</i>	<i>macro</i>	<i>4500</i>	<i>in Pearsall 2008</i>
<i>Arg</i>	<i>Highland</i>	<i>various sites</i>	<i>Zea mays</i>	<i>sg</i>	<i>4500</i>	<i>Babot 2006</i>
<i>Peru</i>	<i>Highland</i>	<i>Huaynuma</i>	<i>Zea mays</i>	<i>sg</i>	<i>4000</i>	<i>Perry et al 2006, 2007</i>
<i>Chile</i>	<i>Highland</i>	<i>Tulan 52</i>	<i>Cf.Zea mays</i>	<i>sg</i>	<i>3850</i>	<i>McRostie 2007</i>
<i>Chile</i>	<i>Highland</i>	<i>Alero toconce</i>	<i>Zea mays</i>	<i>macro</i>	<i>3350</i>	<i>Sinclair 2004, Adan y Urbina 2007</i>

Chile	Highland	Tulan 54	Cf. Zea mays	sg	3300	McRostie 2007
Bolivia	Highland	Chiripa	Zea mays	sg	3000	in Logan 2006
Chile	Highland	Chiu Chiu 200	Zea mays	cob	3000	Benavente 1988-89
Chile	Highland	Tulan 55	Zea mays	cob/kernels	3000	Núñez et al 2006
Peru	Coast	Las Haldas	Zea mays	macro	2990	Ugent et al 1986
Chile	Coast	Canamo	Zea mays	?	2800	Rivera 2006
Chile	Coast	Faldas del Morro	Zea mays	macro	2800	Dauelsberg 1985
Chile	Coast	fase cañamo monticulo	Zea mays	macro	2800	Núñez & Moraga 1983
Peru	Coast	Pampa Rosario	Zea mays	macro	2760	Ugent et al 1986
Chile	Highland	Tulor 1	Zea mays	cob	2600	Llagostera 1984, Baron 1986
Chile	Coast	Caleta Huelen 43	Zea mays	?	2400	Núñez et al 1975
Chile	Valley		Zea mays	macro	2400	Planella et al 2007; Planella & Tagle 2004
Chile	Highland	alero chulqui	Zea mays	macro	2300	Sinclair 2004, Adan y Urbina 2007
Chile	Highland/coast	Tulan 57, 59, 71, 82	Zea mays	cob	2300	Núñez 2005
Chile	Coast	Conanoxa	Zea mays	?	2270	Niemayer & Schiappicase
Bolivia	Highland	Kala Uyni	Zea mays	phyto/sg	2150	in Logan 2006
Bolivia	Highland	Kumi kupa	Zea mays	phyto/sg	2150	in Logan 2006
Chile	Coast	Ramaditas/Guatacondo	Zea mays	cob	2000	Rivera 2006
Arg	Highland	PP9	Zea mays	seeds	2000	Rodríguez & Aschero 2007
Chile	Coast	Alto Ramirez	Zea mays	macro	1900	Dauelsberg 1972
Chile	Coast	Azapa 115	Zea mays	?	1900	Muñoz 2004
Chile	Coast	Guatacondo	Zea mays	cob	1800	Rivera 2006
Chile	Coast	Ramaditas/Guatacondo	Zea mays	cob	1800	Rivera 2006
Arg	Highland	Campo Pucara	Zea mays	macro	1800	Oliszewski 2004

Chile	Highland	Puripica 23, 31	<i>Zea mays</i>	macro	1700	Núñez 2005
Chile	Highland	Ranl 100	<i>Zea mays</i>	cob	1700	Pollard 1971
Arg	Highland	Huachichocana	<i>Zea mays</i>	macro	1500AMS	in Lema 2009
Peru	Highland	Pancan	<i>Zea mays</i>	macro	1500	Smith 1998
Chile	Highland	Tulan 85	<i>Zea mays</i>	cob	1500	Núñez et al 2006
Chile	Coast	Azapa 6	<i>Zea mays</i>	macro	1400	Erices 1975
Chile	Coast	Azapa 70	<i>Zea mays</i>	?	1400	Muñoz 2004, Romero et al 2004
Bolivia	Lowland	Llanos de Mojos	<i>Zea mays</i>	kernel	1400	Dickau et al 2012
Bolivia	Lowland	Llanos de Mojos	<i>Zea mays</i>	phyto/sg	1400	Dickau et al 2012
Chile	Highland	Pichasca	<i>Zea mays</i>	kernel	1025	Rivera 2006
Chile	Coast	Ramaditas/Guatacondo	<i>Zea mays</i>	cob	1000	Rivera 2006
Chile	Coast	Tiliviche 1b	<i>Zea mays</i>	cob	920	Rivera 2006
Arg	Highland	Punta de la Peña 4	<i>Zea mays</i>	macro	700AMS	Rodríguez & Aschero 2007
Chile	Coast	Ramaditas	<i>Zea mays</i>	cob	221	Rivera 2006
Bolivia	Highland	Copacabana peninsula	<i>Zea mays</i>	kernel/cupule	Formative	in Logan 2006

Table 18. Normalised dates (BP) for the appearance of “non indigenous crops” *Zea mays* (sg: starch grain, phyto: phytolith).

The minor proportion of maize in the northern coast of Chile (Ramaditas, Tarapaca, Tiliviche or Alto Ramirez in the Azapa Valley) leads Rivera (2002; 2006) to argue that maize was not cultivated except in quite restricted environments in enclosed valleys. He associates its presence with highland populations and suggests that maize played a relatively minor role in the subsistence diet.

Indeed, many scholars have proposed a non-main staple explanation for the early spread of maize, related to ethnic boundaries and cultural meanings (Bird 1966; Bird 1970; Blake 2006; Burger & Van der Merwe 1990; Hastorf 1999; Iltis 2006; Johannessen & Hastorf 1994; Pearsall 1994; Rivera 2006; Staller 2010), by contrast to the arguments where maize was

seen as the primary catalyst for complex socio-cultural development in the Americas (Willey & Phillips 1958).

Summary

New methodologies and research projects are increasingly filling gaps in the data and the understanding of the process of the onset of agriculture in America. Approaches are not without controversies, such as the validity of early crop microfossils and the timing of spread they represent. Also new AMS dating should be performed in order to conduct a proper reevaluation of the earliest crops. DNA studies can also make clearer the distribution and origins for wild ancestors, though there is a general consensus about the three main areas where they originate: highlands, midlands and lowlands. Accepting a non-conservative view, it seems that crops are present in the area following the Pleistocene climate change, and most of the species known today have been present since at least 5000BP.

For Atacama, scarce crops have been found so far when comparing neighbouring areas (Table 19) (north-western Argentina, northern Coast of Chile and Bolivian Highlands). Whether this reflects cultural options, ecological restrictions or a bias in the register is still not clear (although preservation of botanical remains in the arid Atacama area is generally very good, systematic collection during excavation to insure a good recovery of archaeobotanical remains has been fairly rare). In this sense, the history of the spread of the different crops is overall partial, mainly due to conservation issues and the amount and types of research conducted in different areas. The earliest crops are not necessarily the main staples. In cases such as maize, it is related to status or social boundaries, and for *Lagenaria*, its early presence might be related to its utilitarian role.

PERIOD (ca)	WESTERN ATACAMA PUNA	CHILEAN NORTH COAST	NORTH WESTERN ARGENTINA	BOLIVIA HIGHLANDS
Pre-formative	<i>Lagenaria</i> sp. <i>Cf. Zea mays</i>	<i>Chenopodium</i> sp.	<i>Phaseolus</i> sp. <i>Arachis</i> sp. <i>Amaranthus caudatus</i> <i>Capsicum</i> sp. <i>Cucurbita</i> sp. <i>Cf. Zea mays</i> <i>Lagenaria</i> sp. <i>tubers</i>	
Formative ca.2950-1450BP	<i>Lagenaria</i> sp. <i>Zea mays</i> <i>Cf. Chenopodium quinoa</i> <i>Cf. Capsicum</i> sp. <i>Gossypium</i> sp.	<i>Solanum tuberosum</i> <i>Phaseolus lunatus</i> <i>Phaseolus vulgaris</i> <i>Arachis</i> sp. <i>Erythroxylon coca</i> <i>Ipomoea batata</i> <i>Manihot esculenta</i> <i>Dioscorea</i> sp. <i>Capsicum</i> sp. <i>Chenopodium</i> sp. <i>Gossypium barbadense</i> <i>Lagenaria</i> sp. <i>Zea mays</i> <i>Canna edulis</i>	<i>Phaseolus</i> sp. <i>Cucurbita</i> sp. <i>Lagenaria</i> sp. <i>Zea mays</i> <i>Capsicum</i> sp.	<i>Chenopodium quinoa</i> <i>Chenopodium</i> spp. <i>Chenopodium palladicaulle</i> <i>Tubers</i> <i>Zea mays</i>

Table 19. Crop presence (micro and macro evidences) in Atacama Puna and neighbouring areas.

In the next chapter I will detail archaeobotanical evidence found in the Atacama area among the broader context of plant foodways.

CHAPTER V. Foodways on the western slope of the Puna de Atacama. An evaluation with emphasis on plants.

Introduction

This chapter aims to evaluate in a broad perspective the background related to plant foodways in Atacama. In this sense, it provides archaeological, ethnohistoric and ethnographic information regarding the conceptualisation, procurement, distribution, preparation and consumption (Parker Pearson 2003) of plants. A review is given of the most important edible wild and domestic plants, their cultural use and values, as well as their ecological characteristics. Technologies associated with plant cultivation, processing, manipulation and storage are described and evaluated according to archaeological and ethnographic data (refer to CH. III maps for main archaeological sites and see Figure 12 for other localities mentioned in this chapter). Also, though as a brief review, the relevance of animals, especially camelids, is considered, due to their importance in the local subsistence and foodways. Finally diet is discussed by reviewing kilocalorie models and previous bio-anthropological studies. This latter point also incorporates background data about the isotopic signals of local resources (plants and camelids). Considering that the mobility of populations or individuals might influence the spread of crops and related technologies, I also give local background of $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}$ isotopes.



Figure 12. Map showing major localities and sites named in this chapter. Adapted from Horta (2012, 8).

V.1 Plants

Ethnographic and ethno-historic data

The agriculture of the western slope of the Puna de Atacama is part of an Andean cultural horizon characterised by plant and animal species, cultivation and irrigation techniques, as well as social organisation and rituality, though it also has its own particularities due to its desert condition and the role that legume trees played in the economy and culture of their inhabitants.

-Wild plants

Modern ethnobotany of the area shows that around 80-90% of the wild plants have specific uses such as forage, medicine, staining, crafts, construction, food or ritual (Villagrán & Castro 2004; Villagrán *et al.* 1998a; Villagrán *et al.* 1998b). The most popular and important wild edible plants (see Appendix 3 for some pictures of them) are the pods and fruits of Fabaceae trees *Prosopis* sp. (algarrobo) and *Geoffroea decorticans* (chañar), which grow abundantly in the oases (2100-3100masl). Also fruits from Cacteaceae (*Opuntia* sp. and *Echinopsis* sp.), which grows between 2500-3800masl, and rhizomes and tubers from different species, such as Cyperaceae (*Scirpus* sp., *S. californicus* or *Schoenoplectus americanus*), Balanophoraceae (*Ombrophytum subterraneum*), altea (*Junellia digitata*) from the Verbenaceae family, *Nototriche estipulate* (Malvaceae), which have a thick edible root. Other wild tubers are “cebolla del campo”, taxonomically undetermined; *Tiquilia atacamensis* (kauchal) from the Boraginaceae family, *Hoffmannseggia doellii* (kulchao, mutukuru, etc) from the Fabaceae family, *Pitraea cuneato-ovata* (chámen) from the Verbenaceae family, which some people report as bitter and inedible whilst others claim that it is sweet and edible. Other nutritious plants consumed as fruits, salads or stews are *Lycium humile* (wicha) from the Solanaceae family, with an edible small fruit, which is also used for making aguardiente; *Atriplex* sp. (cachiyuyo) from the Chenopodiaceae family, *Mimulus glabratus* (berro) from the Phrymaceae family and *Tagetes minuta* (soiko) from the Asteraceae family, among others (Castro *et al.* 2004; Munizaga *et al.* 1958; Villagrán & Castro 1997; Villagrán *et al.* 1998a). Some of these latter plants are now despised by local

people but probably played a major role as famine foods (Minnis 1991) and as main foods during the early settlement in this territory (Munizaga *et al.* 1958).

Algarrobo and chañar could be considered to be in a position “in between” a wild and domestic plant due to the continuous manipulation by people. Martínez (1998) says that some ethnohistoric information allows us to classify these trees in a domestic category.

The quechua name for *Prosopis* was *Thaccu* o *Taco*, meaning “the tree”, which reflects its economic, ecological and symbolical relevance (Yacovleff & Herrera 1935)⁷. This also happens with the yunga word *ong*, (Rostworowski de Diez Canseco 1981). Within the Atacama, the name of the tree was *vali* and the fruit *ttacco* (Latcham 1936b, 39). Gunckel states that this tree is Atacameño per excellence (Gunckel 1967, 70). The name for chañar is *cunza*, deriving from the Atacama word *tchaynar* (Latcham 1936b, 49).

Despite the depletion of these resources and the acculturation of local communities, these trees remain highly valuable. On one hand, the density of the hard wood makes it an extraordinary fuel, often prepared as charcoal, the wood is used for crafting and construction, and the trees produce a large quantity of nutritious pods and fruits that can be stored and prepared in different ways. On the other hand, these resources are embedded with ritual and sacred meanings. Moreover, Martínez (1998) proposes that these trees constituted the identifier of the groups that inhabited the Circumpuna, suggesting that gathering more than farming strategies would characterise these groups. Hidalgo (2004), citing Cañete & Domínguez (1787), describes how during the XVIII century, the *ayllus* of San Pedro de Atacama had a special and incredible care for their algarrobales and chañares, because of the interest in their fruits, from which they made their beverages (*quilapana*) with which they got drunk during their parties. Philippi (1860) describes what I consider

⁷ However, Beresford-Jones (2011) states that there is no linguistic citation by the former authors to justify *thaccu* as meaning the tree.

could be evidence of *Prosopis* planted beyond their natural range and could be related at least with protohistoric times. In his “Viage al desierto de Atacama” he refers to several isolated specimens of *Prosopis* near the coast. In Caldera he describes “At a considerable distance from the sea I found a six feet tall algarrobo, *Prosopis flexuosa*” (Philippi 1860, 9) translated by V.McRostie). Then, near Paposo, he describes that in the slope of a hill there is a small stream where fig trees and pear trees as well as an old *Prosopis siliquastrum* are present (Philippi 1860, 21). Early examples of *Prosopis* sowing can also be found in North American deserts. Fray Miguel del Barco (1700, cited in Beresford-Jones 2004, 196), describes that since *Prosopis* trees in Baja California were bitter, they planted sweeter varieties brought from the coast or Yaquis area.

Regarding the collection, storage, processing and social meanings of these trees, there is rather more information for the Argentinian Puna than for the Chilean side, although this data can be useful to make some analogies due to the strong interaction between the two areas in pre-Columbian and colonial times⁸. These fruits mature in summer, from December to March approximately. In Northwestern Argentina the collection of the pods was known as the Algarrobeada, “El tiempo de la Algarroba” or “La alojada” (Arana 1999; Demaio 1988; Latcham 1936b), being a social festivity where mainly woman, but also children and men, went out in caravans to gather the pods. Arana (1999), based on ethno-historic documents, shows how the gathering of algarroba pods in the XVI century was intertwined with the ceremonies and ritual practices of the Indians of the Tucuman plains. Indeed, the time of the recollection was seen by the Spaniards as a time when demons were expressed more strongly, due to the drunkenness produced by the *aloja* (beer made from algarrobo) and the revival of traditional rituals and Indian beliefs.

Due to their seasonal fruting, storage was necessary to preserve those fruits that were not consumed immediately. In Peine, algarrobo pods are dried by sunlight and then are saved in

⁸ Also see Beresford-Jones (2004) for more information about *Prosopis* in Native American groups.

sacos (Núñez 1998), or *tambores* in Guatin (Serracino & Stehberg 1975). A more traditional system uses *trojas* (aerial storage) (Núñez 1995). Underground pits have been documented for Northwestern Argentina (Laguens 1999) and Llagostera *et al.* (1984) found *Prosopis* seeds in what they believe were storage structures in Tulo 1. In North-western Argentina and the eastern United States, people used to toast the pods of *Prosopis* before grinding and storage in order to avoid the common Bruchidae beetle, which infests the harvest (Demaio 1988).

Latcham states that during the years when maize was scarce, Indians collected *Prosopis* pods for making their bread, whilst when maize harvests were abundant, they used the *Prosopis* pods to make *aloja* (*chicha*) and to feed the herds, which is the main use by current towns' descendants from Spaniards (Latcham 1936b, 36). Fernández de Oviedo y Valdés, referring to the trip to Almagro by Atacama, relates how the expedition depended heavily on algarrobo consumption for their maintenance. He describes how the Atacameños produce some maize which they eat while it is still fresh by the middle of the year "and the rest of the time they maintain themselves with garrobas and other dry and squalid fruits from trees...some small" (Fernández de Oviedo y Valdés (1851, cited in Latcham 1936b, 40). Other authors also recount that they ate maize for six months and the rest of the year they were sustained by algarrobo (D'Antoni & Solbrig 1977).

In environments with an abundance of algarrobo, the gathering of this resource has continued alongside the adoption of agricultural production (Arana 1999; Beresford-Jones 2004; Laguens 1999; Noli 1999). Laguens (1999), using modern specimens, exemplifies the high yields produced by these trees. Indeed, since the first Spanish chroniclers, their presence has been highlighted in the feeding of the indigenous population (Latcham 1936b). In Northwestern Argentina, the relevance of algarrobo in the colonial economy was so important that legislators argue that neither maize nor wheat was sufficiently abundant to sustain Indian and Spaniards (Noli 1999, 207). Therefore, this product became part of the tribute from the Indians to the colonial regime. However, this focus on the collection of algarrobo could have been enhanced by the restructuring of agricultural practices and taxation during colonial times (Noli 1999).

On the western slope of the Puna de Atacama, numerous reports talk about the relevance of these resources in the higher belts, where *Prosopis* did not grow naturally; therefore the beans and their produce were important objects for trading: “Caravans of llamas departed from higher Loa to Atacama in March and April when algarrobo and chañar was gathered. The herders conducted 10 to 20 llamas loaded with *charqui* (dried meat), meat and llamas to exchange with them” (Villagrán & Castro 1997, 287). In Socaire (3200masl) algarrobo and chañar would have been traded with lower towns such as Peine and Toconao (Mostny 1954; Munizaga *et al.* 1958, 26) or from San Pedro de Atacama to Guatín (Serracino & Stehberg 1975). In the first decades of the twentieth century, caravans came from Valle Grande, Jujuy Puna, bringing meat, wool and ropes and trading them for maize, chañar, *añapa* and sugar (Madrado 1981). In fact, these resources were classified in a “sweet category”: therefore, in ancient times, to travel from the higher belts of the Loa to the oases in order to get these fruits was totally justified (Martínez 1998). Also from Bolivia, highland Indians came for alcohol and chañar fruits (Riso Patrón 1918, cited in Sanhueza 1992). Núñez (1993) states that algarrobo, chañar and maize still constitute wealth items between highland communities, being used as coins due to their necessity and role in the festivities and rituals of the Andean calendar. Also the wood from these trees was highly valuable due to the construction, crafting and caloric outstanding properties. Núñez (1962) and Vidal (2007) have highlighted that probably the intensification and demands of these trees was also related to these characteristics.

Traditionally, algarrobo pods have been prepared in different ways for all sorts of occasions (Villagrán *et al.* 1998b). In older times children used to eat them raw, though it seems that this causes severe constipation (Gunckel 1967), but it is likely that various processing methods might have diminished this effect. Processing techniques are described by several authors. Fernandez de Oviedo y Valdés (1851) describes that these fruits were ground before being eaten. The most common use is as a flour called *añapa* (Villagrán *et al.* 1998b). It is prepared by grinding the pod and extracting the seeds by sieving. This flour is consumed and prepared as several dishes, toasted or with black maize flour (Villagrán *et al.* 1998b). Also the flour can be mixed with water, which is known as *cocho* (Pardo & Pizarro 2005) or the seeds can be left in water, resulting in a sweet beverage (Villagrán *et al.* 1998b).

Latcham (1936b) states that in general, the Indians did not eat these pods raw, but processed them as bread or *aloja*. This bread was known as *patay* in Atacama and North-western Argentina. Quevedo and Pelleschi (1886, cited in Latcham 1936b, 47) describe how *patay* is made in Argentina. After the pods are collected they are dried in the sun. Then they are pounded until flour is produced, which is sieved to separate the fine parts from the coarse ones. The latter are saved for feeding the livestock during winter, whilst the former is mashed and built into bricks or circles and toasted. Another process mentions that the flour is put in a hot vessel or near the fire, covered with a fine layer of sand. After ten minutes, the *patay* is ready. The latter operation serves to melt the abundant natural sucrose contained in the flour; afterwards it becomes as solid as cement.

Aloja or *chicha* is very important in traditional festivities and reunions. It is not just an alcoholic beverage but also a very nutritive staple and it has medicinal properties. This beverage is prepared by grinding the dry pods in a stone or wooden mortar, putting them in a vessel with mild water. Fermentation occurs from one day to another (Mostny 1954). In Socaire, Hidalgo (1992) says that the algarrobo was pounded in big barrels, then warm water was added and the fermentation occurred in 24 hours. Another description for preparation is to leave the pods in warm water whilst constantly stirring (Serracino & Stehberg 1975). Falkner 1974, cited in (Pardo & Pizarro 2005) specifies that ground pods were left to ferment in cold water for around 12-24 hours afterwards, obtaining *chicha*. Rosales (1877) states that wine, honey and vinegar were made from algarrobo and chañar. In Socaire, *aloja* was mixed with toasted flour, making the nutritive *ulpo*, which was consumed at community events (Hidalgo 1992). Different authors (e.g. Falkner 1974; Fourlong 1969; Montenegro 1945, cited in Pardo & Pizarro 2005) state that algarrobo *chicha* has diuretic and properties that are beneficial to the stomach. The pods and leaves are widely used for feeding animals, especially now that its human use has been replaced by other foreign foods. The resin of this tree was used as a stain producing a garnet colour when used alone and brown when mixed with other plants. The charcoal from its wood provides a long-lasting and highly caloric fuel. Due to its hard characteristics, the wood it is also highly valued for making all kinds of tools and constructions. For instance, big trunks are hollowed and used as mortars named *tacana* (Villagrán *et al.* 1998b).

The fruit of chañar can be eaten raw or cooked. One of the main preparations is *arrope*, in which the fruit is boiled, sieved and keeps on boiling until is ready. This liquid requires the sweetest chañar, as the fruit of individual trees vary, the sweetest fruiting trees are known by locals. Also it can be prepared as a dessert by toasting the fruit, wetting it and sieving it. Afterwards sugar and goat's milk are added (Villagrán *et al.* 1998b, 64). Bertrand (1885, cited in Latcham 1936b, 49) says that "Chañar is greatly liked by the Atacama Indians, who prepare large quantities for winter storage, conserving it after boiling" (translated by V.McRostie). The fruits and leaves are excellent forage for animals, as well as their wood for making tools, for different constructions and for fuel.

A detailed study regarding chañar and algarrobo determines that these resources have 1) a high protein value, 2) a low temporary investment in their elaboration, 3) a considerable yield, simple instruments needed for their production and 4) can be used to prepare a wide range of meals (Figueroa & Dantas 2006, 35), translated by V.McRostie). Also, although their availability is seasonal, they can be stored for up to twelve months for raw pods or flour of algarrobo and twenty-four months for the *arrope* of chañar (Figueroa & Dantas 2006).

As mentioned earlier, other edible wild plants, although almost unused today, are *Scirpus* sp., *Opuntia* sp. and *Echinopsis* sp. The most widely documented way of eating the fruits of *Echinopsis* sp. and *Opuntia* sp. in the area is raw. In Atacama the fruit (*pasakana*) of *Echinopsis* is eaten raw and its wood is highly valuable in constructions and handcrafts, as well as the spines for weaving and other manual labour (Villagrán *et al.* 1998a; Villagrán *et al.* 1998b). *Opuntia* fruit was used as a medicine when dissolved in water after sieving the seeds and rinds (Villagrán *et al.* 1998a). Analogies from other areas allow us to explore more elaborate preparations. Holden (1991), based on several ethnographic descriptions, has described different processes for preparing the *Opuntia* fruits. They can be stored and used for the starch content of their seeds. After being dried, they can be threshed, beaten to remove their fibre or pounded prior to the preparation of a meal, which could be either eaten dry or made into gruel, beverage or bread. Also the pulp could be scraped out and dried for storage. Throughout the Southwest of North America, native groups, including agriculturalists, gathered tunas for use as both a fresh fruit and a dried preserve. Castetter and Bell (1935, cited in Riley 2010) also report groups grinding the dried fruit, including the

large and abundant seeds, into flour with maize, which is eaten as gruel. These large and sweet fruits do not appear to have been a staple for the agricultural groups studied by Castetter and Bell, but rather, a seasonal supplement and sweet treat. This is contrasted with the importance of this species in Mexico, where varieties with larger fruit are an important commercial crop. Riley (2010), based on coprolite analyses from the Lower Pecos canyonlands, concludes that prickly pear tunas was a seasonal staple. Tunas have low processing costs and a caloric return that surpasses the other plant staples of the canyonlands. This suggests that tunas would become the primary focus of the regional subsistence strategy whenever they are available and abundant (Riley 2010). Regardless of the degree of importance, it is certain that most or all native groups living in the greater Southwest utilised the fruits of the prickly pear (Beals 1973, cited in Riley 2010). In Mexico the young cladode, segments of *Opuntia ficus-indica* and of almost all *Opuntia* species are edible after being carefully peeled to remove the spines. This vegetable contains dietary fibre, vitamins and minerals, such as magnesium, potassium and calcium (Nopal Cactus N.D.), although the latter may not be biologically available because it is present as calcium oxalate, a non-absorbable complex in the intestine (McConn & Nakata 2004). This abundance of oxalates has been recorded from Archaic coprolites of numerous sites in the Pecos region, Texas (Danielson & Reinhard 1998). Nopales were much less important as a food resource across the Southwest than tunas (Basehart 1974; Riley 2010). Accounts indicate that nopales were primarily used during the winter or as a starvation resource by native groups. The pads, and occasionally unripe tunas, were generally roasted directly in coals and used to supplement cornmeal or other resources (Castetter and Bell 1935, cited in Riley 2010).

There are various species of wild edible tubers, rhizomes or thick stems. “The term roots and tuber is a convenient handle use to describe any swollen vegetative storage organ – root, rhizome, corm, tuber, stolon, etc.-” (Hather 1994, 719). For instance, Cyperaceae species for the area are identified as *Scirpus californicus* (C.A. Mey.) Steud., *Scirpus deserticola* (Phil.) and *Scirpus* sp. (Villagrán *et al.* 1998a), and also *Scirpus atacamensis* (Villagrán *et al.* 1998b). Holden (1991) and Aldunate *et al.* (1983) identified *Schoenoplectus americanus* (syn. *Scirpus americanus*). All of them grow in meadows or river/ravine beds.

Ethnobotanical knowledge categorises them as forage and/or basketry material, though several worldwide ethnographic and ethnoarchaeological examples characterise them as important in diet and prepared in different ways. *Schoenoplectus americanus* and/or *Scirpus* sp. rhizomes and shoots could have been ground to make flour, or rubbed and roasted to remove fibres before grinding into flour. “The stems would be cut off, the tubers and probably other parts of the rhizome kept for processing by pounding or grinding and the remaining parts of the plant discarded or later reused for fuel, baskets, roofing, animal fodder etc” (Holden 1991, 326). In various papers, Wollstonecroft (2007; 2009) Wollstonecroft *et al.* (2008; 2011) highlights the role of *Bolboschoenus maritimus* and other *Scirpus* species, which have been used as food from as long ago as 18000BP in the Old World “This plant has edible seeds, tubers and shoots and commonly grows in large stands, making it a readily accessible and possibly nutrient-rich resource” (Kantrud 1996, cited in Wollstonecroft & Erkal 2003). Even if these rhizomes could have been eaten raw, tubers were usually ground prior to consumption (Wollstonecroft 2009, 129.) Also, besides the tubers and/or rhizomes the seeds, pollen, stem bases and/or shoots would have been consumed (Wollstonecroft 2007, 201), though Heiser (1978) and other authors cited by him (e.g. Cobo 1890; La Barre 1948; Parodi 1933) refer mainly to the roots, which are white and tender, as the edible part. For the Titicaca area, *Scirpus californicus* (totora) culms are pulled from the water and broken from the rhizome, and the basal part (20 to 30 cm) is eaten raw after the outer layers are peeled away (Heiser 1978, 228). Cárdenas (1969) refers to *Scirpus riparius* as “totora”, of which Indians like to eat the basal part after peeling the epidermis with their nails. This part is tender and white. Indeed, he states that this product is offered for sale in Titicaca market and that its shoots are even better than celery. References for the consumption and preparation of Cyperaceae roots or rhizomes are also given for North America (Messner 2008).

Hoffmansseggia (doelii) tuber is very abundant in the Atacama. It was a sweet foodstuff for the *abuelos* (Villagrán *et al.* 1998b). It is a frequent “rain grass” in the semi-desert sands. Children eat it raw, although it can also be eaten boiled. It has good taste, being sweet and milky. Though not all the tubers are good, the sweet ones are available and extracted just from some places. The aerial part of the plant is excellent forage (Villagrán *et al.* 1998a).

Munizaga *et al.* (1958) state that this tuber was eaten by the herders. *Nototriche estipulata* and *Junellia digitata* have white and tender roots; which in ancient times were eaten and cultivated. *Tiquilia atacamensis* also has an edible root and *Ombrophyton subterraneum* inflorescence and roots are greatly prized as food. They grow in rainy seasons in sandy and humid soils, where the biggest and tastiest roots are found. For highland herders of the XV Region of Chile (Arica and Parinacota), *Ombrophyton subterraneum* was the only fruit they had ever known during their infancy (Pardo 2007). It is described as juicy and fresh, sometimes sweet, but sometimes bitter (Aldunate *et al.* 1983; Pardo 2007; Villagrán *et al.* 1998a; Villagrán *et al.* 1998b), Munizaga *et al.* (1958) also mention different wild tubers, such as *cebolla del campo* in Socaire or *kispur* in Peine.

-Crops

The cultivation of crops in the Andes is strongly conditioned by the altitudinal belts as discussed in chapter 4. In ranges higher than 3300masl, pseudo cereals and tubers such as potato, oca, ullucu and mashua were grown together on the fields. Below 3000masl, pseudo cereals and around 2600masl tubers start to gradually decline, so that different proportions of tubers, pseudo cereals and maize plantations are grown at different altitudes. Below 2600masl, maize, beans and cucurbits were predominant as cultivated crops (Montaldo 1974). However, the geography of the Atacama implies that rather than big extensions of fields, crops were cultivated in small and scattered micro-niches, which usually supported the presence of just one household (Martínez 1998).

In the western slope of Atacama, the ethnographic and ethno-historic data repeats as common crops maize, potatoes and quinoa. Beans and cucurbits are mentioned, but there are no specific descriptions about their cultivation or consumption.

In the oases and ravines, the traditional products still planted are mainly maize, beans and Cucurbitacea varieties, though foreign crops such as *Medicago sativa* (alfalfa), pears, figs and other vegetables predominate nowadays. Bibar (1966 [1558], cited in Zapater 1976-77) during the XVI century describes the main products that Atacameños consumed in the Salar de Atacama: maize, potatoes, beans, quinoa, algarrobo and chañar. Vazques de Espinoza (1629, cited in Zapater 1976-77) describes the crops planted in Toconao as maize, wheat,

algarrobas, potatoes, grapes and other fruit trees. He also mentions Catarpe as a fertile little valley. Other colonial descriptions describe Atacama La Baja (Chiu Chiu and Loa communities) as non-fertile and without cultivable land. "Therefore Indians with extreme effort must build terraces to plant...and this is more for fun than for fruit return due to the continuous frosts..." (Espejo 1683, cited in Hidalgo 1984, 313), (translated by V.M.cRostie). Del Pino Manrique (1787, cited in Zapater 1976-77) describes San Pedro de Atacama (Toconao, Socaire, Peine, Susques and Incaguasi) as lacking in any food. These are brought from the Tucuman valleys in Argentina. Although, later he mentions that they do in fact produce wheat, maize, some vegetables, fruits and algarroba, which they use to make chicha, as Peru does with maize. One century later, Bertrand (1885, 241) refers to the oases of the western slope of the Puna de Atacama as planted with a large amount of alfalfa (*Medicago sativa*) and extensive cornfields. He says that beans do not seem to develop well and that potatoes and onions are brought from Chile (south of parallel 24), though with careful cultivation they can be produced in Toconao and Peine, where the waters are more suitable for these kinds of crops. In the eastern oases of the puna, alfalfa and maize are cultivated on a large scale, with the latter being very beautiful, sweet and tender. Philippi (1860, 53) (translated by V.McRostie) states that "vegetables are rare to find on the square of San Pedro de Atacama. Barely squashes and maize and even potatoes are scarce". He did not see quinoa or oca, which he says are cultivated in the highlands of Bolivia.

These differences in the descriptions regarding the products planted and/or obtained in the area could be a condition caused by the post-conquest re-organisation, however it might be an approximation that allows us to visualise which crops were suitable to cultivate in the lower oases.

Ethnographically, Villagrán and Castro (1997) report that in the higher belts of the Loa subarea, such as Incaliri and Toconce (3350masl), *Chenopodium quinoa* was planted in small plots in nearby meadows and grass areas where herding activities were performed. In all of them, tubers and maize were planted (Martínez 1998). Indeed, maize and potato plantations have been recorded in Incaliri at 2900masl and Caspana at 3200masl in the Salado River. Also between 3500-3800masl, up-water of the Toconce River, and at higher altitudes than San Pedro oases; maize and tubers are still planted (Villagrán & Castro 1997).

Castro (2008) describes the seasonal works and rites associated with crops in Ayquina and Toconce. From January until June, maize and potatoes are harvested. In June, storage is performed by controlling the process of dehydration of tubers and beans, as well as the production of maize flour for the coming months. The first of August is the beginning of the new agricultural year in the Andes, starting the planting of the seeds again. Scarce ethnobotanic studies provide some information about the different varieties of crops planted in the area. Munizaga *et al.* (1958) describe for Socaire twenty denominations for maize types, thirteen for potatoes and two for quinoa. They also register foreign crops such as carrots, garlic, hortalizas and alfalfa, amongst others.

Regarding maize, the Atacamas distinguished around six to seven varieties (Mostny 1954). The local varieties of maize are capio and morocho (Gundermann & González 1995; Núñez 1998). The first one is a soft maize, used mainly for toasting, and the second, also called Amarillo, is harder and is used for toasting and for thickening soup (Núñez 1998). Munizaga *et al.* (1958) generated a preliminary report of the potential varieties of maize found in Socaire at the south-east of the Salar de Atacama, at 3700masl (amarillo, chejcecito, blanco, pokoi, pisangallo, rosado, blanco, negro, azul and kebir). Latcham (1936b, 130) also provides information about the local varieties. He states six varieties (patascka, seltitanti, ckakeltanti, tarartanti, ayintanti, tantichari), of which patascka, also known as morocho, curahua or pululo, is the most widespread. It was preferred for its good quality to make flour, high yield, colour and texture. Therefore it was planted mainly for this purpose (Latcham 1936b, 131). He also states that most of the indigenous varieties mature in four months. Most of the communities have some variety of maize suitable for storage (Villagrán *et al.* 1998b). From archaeological findings, we can name the following races in the area: morocho, polulo and capio chico Chileno (Latcham 1936b; Mangelsdorf & Pollard 1975; Uhle 1913).

Regarding potatoes, these are not grown in the oases, at least today, seemingly due to the lack of water. In this sense, maize is more resistant and can cope with water turns that sometimes last fifteen days. If water is too scarce during cultivation, the productivity of the tuber is extremely low, as they have a poor radicular system: therefore, water is necessary for maintaining the osmotic pressure which is essential for the photosynthesis process. Therefore potatoes need to be irrigated abundantly. Also if the salinity of the soil is too high,

it will harm the tuber (J. Kalazich pers. comm. 2011, translated by V.McRostie). In fact, potatoes are not recorded in this area by the Consecol database (1988), though Gundermann and González (1995) state that they represent 0.2% of the crops planted in San Pedro oases. The Atacama name was *chusli* (Litcham 1936b). Litcham says that in Bolivia and North-western Argentina, the varieties were derived from *Solanum montanum*, which cannot be grown below 2500masl, although he also states that varieties derived from *Solanum tuberosum* were grown in northern Chile and Peru. In this sense, these could be the varieties Litcham says were cultivated below 2000masl, due to their intolerance to cold and altitude. Montaldo (1974) defines ecological areas in Chile where potatoes are grown. In northern Chile, he just mentions the mountain valleys of Tarapacá above 3000masl, where potatoes are cultivated under irrigation systems between summer and autumn, and these are from the series *Andigena* Buk. (Montaldo & Sanz 1962).

Munizaga *et al.* (1958) refer to wild tubers as an important source food. Also, they name domestic varieties of potatoes for Socaire (ajsuca, amarilla, blanca, colorada, chalalar, chucara, morada, negra, pauna, sallama). These potatoes were stored underneath the ground and the surplus was used to trade for fruits from lowland oases. They are also associated with different festivities. Also *Ullucus tuberosus* (ulluco) seems to be cultivated above 3000-4000masl in Atacama Puna (Parodi 1966).

In the oases, local people do not recall quinoa plantations, “since it grows in higher belts”. It is interesting that Philippi tried to cultivate Atacama varieties in Santiago without positive results (Litcham 1936b, 169). In Socaire, people refer to quinoa as extremely tolerant and of high yields. Boman (1908) says that in the Atacama and Jujuy Punas, agriculture was almost null, quinoa being the most reliable crop. Litcham (1936b) mentions that in Atacama, they cultivated the purple variety, called secksaholor, and the ashy variety, called holor. They also planted the white and pink varieties (Litcham 1936b, 149). Munizaga *et al.* (1958) describe two varieties (blanca and colorada).

In Chile there are two different landraces, the altiplano and lowland quinoa. The former is cultivated above 3500masl at 18-22°S without artificial irrigation whilst the latter is cultivated in southern Chile below 1000masl under annual precipitation of 400-2000mm a year (Fuentes & Bhargava 2011, 125). Current experiments measuring the growth of quinoa

in arid environments (Iquique and Coquimbo/Ovalle) have shown that the yield assessment is low, probably due to the negative effects of the high-temperature stress around flowering (Fuentes & Bhargava 2011). Martínez *et al.* (2009) also assess that better yields will need some irrigation and addition of organic matter. Both claim that genetic varieties should be tried in order to produce better yields under extreme aridity. However, it seems likely that in the past people from the oases would have preferred to use trade or other mechanisms of interaction to have access to this crop.

Other crops that archaeologically are ubiquitous include *Lagenaria siceraria*, which intriguingly is not mentioned in most of the ethnographic or ethnohistoric literature. Latcham, though, says that gourds were cultivated throughout the upper course of the Loa river (Latcham 1936b, 206). However, the Cucurbitaceae family is highly plastic in its adaptations, and therefore could be feasible to grow in gardens during the Formative (V. Lema pers. comm. 2013).

Regarding preparation of these crops, there is a similar tradition throughout the southern Andes. *Chuño* was prepared by freeze-drying potatoes in the highlands (Cárdenas 1969; Castro 2008; Pardo & Pizarro 2005). This preparation allowed the storage and transportation of dry tubers throughout the Andean range, these being a main staple during pre-Columbian times (Latcham 1936b). Maize, potatoes and quinoa could be eaten boiled, toasted, as flour, bread or chicha (Latcham 1936b). Though in Atacama there are references just for *chicha* maize preparation. This was prepared by chewing and pounding the kernel and then leaving it to ferment with water (Latcham 1936b, 142). The name given by the Atacameños was *cachir* or *chatchir* (Bahamondes 1978; and Gómez and Siarez 1995, cited in Pardo & Pizarro 2005). In the Loa and Salar de Atacama regions, maize *chicha* is drunk during various different ceremonies (Mostny 1954; Villagrán *et al.* 1998a).

From this review, we can establish what lines of archaeological evidence we could expect for each of the resources mentioned above (Table 20).

<i>Plant</i>	<i>Harvest/Gather</i>	<i>Preparations</i>	<i>Part used</i>	<i>Not eaten part</i>
<i>Geoffroea decorticans</i>	Nov-Jan	Raw, boiled, toasted, ground,	Fruits	Seed, endocarp
<i>Prosopis</i> sp.	Feb-April	Raw, boiled, toasted, ground, fermented	Pods	Seeds sometimes
<i>Opuntia</i> sp./ <i>Echinopsis</i> sp.	April-May	Raw, ground	Fruits/pads?	Spines, seeds?
<i>Scirpus</i> sp.	All year	Raw, ground	Rhizomes Seeds	Stems, seeds?
<i>Hoffmanseggia</i> sp.	April-May	Raw, boiled	Tuber	Stem, inflorescence
<i>Zea mays</i>	Late February-June	Raw, boiled, toasted, ground, fermented	Kernel	Cob, husks, stems
Beans	Summer	Boiled	Seed	Pod, leaves, stems
<i>Solanum</i> sp. (tubers)	August-Sept	Boiled, toasted	Tuber	Stem, leaves, inflorescence
<i>Chenopodium</i> sp.	Feb-June	Boiled, ground	Seed	Leaves, stem, inflorescence other than seed
<i>Capsicum</i> sp.	Summer	Raw	Fruits	Seeds, stems, leaves
<i>Cucurbitaceae/Lagenaria</i>	Summer	Boiled?	Flesh, rinds, seeds	Stem, rinds

Table 20. Foodways and seasonal availability of local edible traditional plants.

Below I will review in more detail the archaeo-botanical data and the artefacts linked to plant processing in the area.

Archaeobotanical data. Macro-remains, micro-remains

Archaeobotanic techniques have been applied unevenly through sites and periods in the Atacama (if they have been used at all). Therefore it is hard to obtain accurate taxonomical and/or abundance measurements that allow comparison and evaluation of the relevance of certain resources within and between sites. However, most of the reports provide nominal measurements and emphasise the absence or presence of those resources which are considered important for the subsistence of these populations, such as algarrobo (*Prosopis*), chañar (*Geoffroea*) and crops. In table 21 I present a summary with the archaeological data regarding botanical and technological evidences recovered from the main sites of the Late Archaic and Formative period within the Atacama. Within this review, original dates were normalized to BP by adding or subtracting 1950 to BC/AD. Refer to maps in CH. III and Figure 12 for location of archaeological sites and places named.

-Wild plants

Algarrobo and chañar have been proposed as the main foods for the area, despite the fact that they seem to have a low ubiquity, especially in Late Archaic sites as well as Formative sites (Aldunate *et al.* 1986; Belmar & Quiroz 2005; Druss 1976; Holden 1991; McRostie 2007; Núñez 1994; Vidal 2007). Experiments carried out to define the residual patterns of pods and seeds after traditional techniques of *Prosopis* preparation in Catamarca, Argentina showed that “the majority of the *Prosopis* archaeological assemblage is considered to represent a very low proportion of the ancient processed volume of each dynamic context” (Capparelli 2008, 175). Although seeds, particularly if they were charred could survive in archaeological contexts (Llano and Ugan 2009), nonetheless with most traditional preparations of algarrobo and chañar requiring grinding and in the case of chañar boiling, there may well be a bias against their preservation in the archaeological record. Nevertheless, in my personal fieldwork, mainly in Tulan within Late Archaic and Formative sites, I have seen that organic plant remains are extraordinarily well preserved: indeed, some stratigraphic levels are mainly composed of shrubs and plants, though chañar and algarrobo are almost entirely absent (McRostie 2007; 2008), and even if processing techniques could damage these remains, I would expect some “accidental loss” or stored pods to survive and reflect their relevance.

Toward the end of the Early Archaic period (ca. 8870-8590BP) in Tulan 67 and Tambillo there is scarce chañar (Núñez *et al.* 2002-2005). During the Late Archaic period in Tulan 52 (4270- 3780BP), scant macro-remains of chañar and algarrobo have been found between *Scirpus* and *Opuntia*, which predominate in the assemblage among other shrubby plants (McRostie 2007; Núñez 1992; 1994). In sites of the Chiu Chiu complex in the Middle Loa, only Cyperaceae seeds and rhizomes have been identified (Druss 1976). *Echinopsis* seeds have also been found in Late Archaic and Early Formative sites in the Vilama River and the Tulan gorge (McRostie 2007; Vidal 2007).

During the Early Formative period, sites such as Chiu Chiu 200 and Tulan 54, 55, 67 present low quantities of both *Prosopis* and *Geoffroea* macro-remains (Benavente 1988-1989; McRostie 2007) and Ghatchi 1A and Calar in the Vilama river present scarce *Prosopis* and

Geoffroea, rising significantly through later periods (Vidal 2007). This trend is also visible during the Late Formative when *Prosopis* acquires more ubiquity in Tulan 85 and Tulan 57 (McRostie 2008). Tulor 1 (Barón 1986; Llagostera *et al.* 1984) has both legumes, and Puripica 31 and Ranl 100 have *Prosopis* (Núñez 2005; Pollard & Drew 1975).

Other edible fruits of wild resources have been found, such as *Opuntia* sp., *Echinopsis* sp, and *Scirpus californicus*. *Opuntia* and *Scirpus* were recovered from gut contents in bodies from the Tulan 58 cemetery (Holden 1991) and were abundant in sites from Tulan and to a lesser extent in the Vilama River (Holden 1991; McRostie 2007; Núñez 1992; Vidal 2007). Although *Scirpus* could have been used for crafting or foraging, Holden (1991) suggests that at least in Tulan 54, they were processed by pounding or grinding (Holden 1991, 326).

Other wild plants recovered in the archaeological contexts (e.g. *Thessaria*, *Atriplex*, *Ephedra*, *Cisthante*, *Tiquilia*, *Acantholippia* and *Cortadera*) are not directly related with food and in most cases are mentioned only briefly. However, most of the surviving plant evidence points to an environment that was not significantly different to today's (Holden 1991, 324).

-Crops

As I briefly reviewed in the discussion of the entrance of crops to South America, for the western slope of the Puna de Atacama, there is scarce evidence of crops during the Late Archaic and Formative periods. Below, I will discuss in more detail their contexts and characteristics.

Lagenaria sp.

The rind of this specie is the earliest evidence for crops found in the area. Rinds are found in the Late Archaic site Tulan 52 (4340±95/4270±80BP) (McRostie 2007) and through all the Formative phases in Tulan (Lema 2009; McRostie 2007; 2008; Núñez *et al.* 2009). They are also present in the Early Formative context of Chiu Chiu 200 (Benavente 1988-1989) as well as in several Formative and later contexts of the Loa and Salar de Atacama sub-area, either plain or decorated using pyrography (Agüero 2005; Aldunate *et al.* 1986; Bittmann *et al.* 1978; Llagostera *et al.* 1984; Mangelsdorf & Pollard 1975; Núñez *et al.* 2009; Pollard 1971; Tarragó 1989; Thomas *et al.* 1995; Vidal 2007).

Due to its hard rind, it was probably used as a container, with a special relevance during the pre-ceramic period. Therefore, this crop should be considered more as a technology than an edible product, though its seeds could have been eaten for their oil.

Zea mays

Starch grains attached to *manos*, conical and flat mortars of the Late Archaic site Tulan 52 (4340±95/4270±80BP) and Early Formative site Tulan 54 (3080+70/ 2380+70BP) have been reported from my earlier work (McRostie 2007). These grinding tools were recovered from stratified contexts (Núñez *et al.* 2002-2005). Surprisingly, no macro remains of maize were found at these sites. Therefore the presence of starch grains exclusively in the grinding tools, the lack of macro-remains and the ritual characteristics of the sites allow us to make the preliminary proposal that this crop was used on special occasions and as a processed product, probably *chicha*. Nevertheless, these preliminary identifications might need reevaluation.

The earliest macro-remains of maize cobs (n=3) associated to *Lagenaria* sp. rinds are reported in the Middle Loa River in Chiu Chiu 200 in a stratum dated by 2910BP (Benavente 1988-1989). No variety or more accurate descriptions have been made, and the author suggests that they were entering the area with foreign groups related to the San Francisco Culture from the lowland valleys of North-Western Argentina.

Also in the southern edge of the Salar de Atacama in Tulan 85, maize cobs were reported in a stratum dated to 2710BP (Núñez 1986-1987). The author suggests that these specimens were cultivated in the nearby oases (Núñez *et al.* 2006), though no evidence of cultivation has been found so far (Núñez *et al.* 2002-2005). In the Late Formative layers of Tulan 85, McRostie (2008) identified cob remains tentatively as a pop corn variety.

Mangelsdorf and Pollard (1975) propose that the earliest agricultural sites are located in the Middle Loa terraces. In the site known as Ranl 100, they recovered several cobs from a stratum dated around 1845BP. These authors recognise three varieties of maize: capio chico Chileno, polulo and chutucuno chico, which are related to Peruvian varieties (Mangelsdorf & Pollard 1975, 66). In the oases of San Pedro, only Tulo 1 presents maize cobs during the Late Formative (2350BP-1850BP), although in scarce quantities and without taxonomical

description (Barón 1986; Llagostera *et al.* 1984; Núñez 1986-1987; Vidal 2007). Other cobs in the oases have been re-evaluated as part of the Middle period (Vidal 2007). In Topater maize has been reported by 2050BP (Thomas *et al.* 1995).

Capsicum sp.

One seed of cf. *Capsicum* sp. was found in gut content in Tulan 58 cemetery (1550-1770BP), though it was smaller than modern specimens (Holden 1991).

Chenopodium sp.

Has been reported in Early/Formative sites such as Chorrillos, Tulan 54, Ghatchi, Topater (Belmar & Quiroz 2005; McRostie 2007; Sinclair 2004; Thomas *et al.* 1995; Vidal 2007) and during the Late Formative (1550BP) (Pollard 1971). Nevertheless, no modern studies have been carried out using these specimens in order to evaluate whether they are domesticated varieties. The only domesticated chenopod reported in ethno-botanical works of the area is *Chenopodium quinoa* (Villagrán & Castro 1997; Villagrán *et al.* 1998a; Villagrán *et al.* 1998b; Villagrán *et al.* 2003). Quinoa, like tubers, might have suffered methodological biases due to the lack of fine sieving and flotation in early research.

Tubers and beans

Tubers are not recorded in the sequence apart from tuber-like starch grain attached to a lithic hoe from Tulan 55, though its context is not securely dated (McRostie 2007). *Solanum tuberosum* and *Phaseolus* sp. are named as part of the “Atacameño crop baggage” during Lasana Complex (after 1550BP) when intensive agriculture is assumed to have been under full development (Pollard 1971), though no archaeological specimens are described. In Topater cemetery (2360BP), Thomas (1995) reports beans, although no more details are given.

Gossypium sp.

Its fibre is described for Chiu Chiu 200 (2910BP) and Tulan 109 (2730-2330BP) (Benavente 1988-89; Núñez *et al.* 2006).

V.2 Technologies associated with plants⁹

Grinding stones

Despite the abundance of grinding stones since the Early Archaic in Atacama, these artefacts have not been properly studied. Until now, researchers have assumed they were used for bone, mineral and mainly wild plant processing, particularly the nutritious legumes of *Geoffroea* and *Prosopis* sp. trees (Carrasco 2003; Munizaga *et al.* 1958; Núñez 1974; 1992; 1995), although descriptions also mention plant grinding by foot pressure in wooden mortars (Latcham 1936b).

In most cases, these instruments are rarely discussed and described in archaeological reports. Some morpho-functional analyses have been conducted on ground stone tools from Tulan 54 during the Early Formative period (Gutiérrez 2004) and from different sites dating to the later periods (1150-450BP) (Carrasco 2003; Cornejo 1990). These latter works distinguish between different types of grinding tools, their differential wear and their spatial distribution. The main categories found in the area are classified by the active features: *manos*, and passive features: morteros and conanas. Morteros are characterised by a conical base that allows vertical or circular movements, whilst conanas have extended flat bases allowing horizontal movements (Figure 13). The *manos* present differential wear on their faces depending on whether they were used horizontally (grinding with a rubbing action) and vertically (pounding with a crushing action). Carrasco (2003) provides an interesting discussion based on the frequencies and varieties of grinding tools in relation to crops and wild resources found in different sites of the later periods. He proposes that these different patterns might be reflecting different 'identities'. Although he acknowledges that

⁹ Refer to Appendix 2 for artefacts images

this proposition may be too precipitated, he suggests that social organisation will be reflected in technological and economic options (Carrasco 2003, 17).

Conical mortars are recurrent in Late Archaic sites in the Upper and Middle Loa as well as in the Confluencia area (Loa-Salado) (Aldunate *et al.* 1986; Druss 1976; Jackson & Benavente 1994; 2010). Also in the Salar de Atacama ravines their presence is abundant in Tambillo, Tulan and Puripica/Vilama and Calarcoco (Núñez 1992; Núñez *et al.* 1995-96; Serracino 1985). Because these conical mortars are usually found in Archaic contexts, they are primarily associated with the earlier periods; however, they might also represent different functions such as the pounding of certain resources (Cornejo 1990) and they are found to a lesser extent in Formative sites (e.g. Tulan 85, Tumor 1). The conanas or flat mortars appear for the first time during the Early Formative (2950BP) in Tulan (Tulan 54, 122) and in the Middle Loa during Vega Alta I (Chiu Chiu 200, RanL), becoming gradually predominant during the Late Formative (Tumor 1, Puripica 7, 23) and afterward. This shift from conical to flat mortars has been associated with the start of horticultural production (Agüero 2005; Núñez 1994; Sinclair 2004). However, they are not present in all of the Formative sites; for instance, they are not ubiquitous in the Vilama River and are rare in the San Pedro oases. Considering the grinding locations, especially during the Late Archaic and Early Formative periods, the concentrations of grinding tools are not in the oases where algarrobo and chañar grows today.

The only evidence of resources processed in the grinding tools is from residue analyses conducted once in Tulan 52 (Late Archaic) and Tulan 54 (Early Formative). In both sites, abundant maize starch grains were found (McRostie 2007); however, in gut and coprolite analyses from Tulan 54 and 58, Holden (1991) did not find maize, but wild plants such as *Opuntia* and *Scirpus*, which were processed before consumption due to their fragmentary condition as well as the different tissues found.



Figure 13. Conical mortar Kalina and flat mortar Tulan 122.

Previous research on grinding tools has identified several implications regarding morphology, use and function. Multiple authors have related morphological differences as indicative of subsistence changes (e.g. Bartlett 1933; Gladwin *et al.* 1938; Hard 1990; Martin 1972; Plog 1974; Woodbury 1954, cited in Adams 1993). “The inference is that these changes reflect an increasing reliance on cultigens, specifically corn” (Adams 1993, 333). The most widely accepted idea regarding morphological changes in grinding tools is that flat surfaces require less effort in the grinding process, making it more efficient (Adams 1993). In this sense, Latham (1936a), referring to maize grinding, describes:

“They did not ground in mortars, although they knew them, because in them the grinding is done by banging with the arms: whilst with weight of the half moon shape, what was beneath was ground easily and the Indian manoeuvres it effortlessly, sliding it from one edge to the other...” (Latham 1936b, 144), (translated by V.McRostie).

However, half moon shape seems to recall the active section, and so far I have not seen this type of *manos* in the area, at least for the periods under research.

Some authors have correlated the level of agriculture dependence with the size of grinding tools and their frequency (Lancaster 1983; Martin and Rinaldo 1947; Martin and Plog 1973, cited in Mauldin 1993). Nevertheless, more than agriculture dependence, it seems that “the length of the grinding surface of the *mano*, or metate grinding area, is positively correlated with the time required to process grain...as the size of the grinding area increases, the time required to complete a task shrinks” (Mauldin 1993, 319). Increased grinding surface area on *manos* and metates promotes grinding efficiency and thus is the driving force behind the

change in *mano*-metate morphology (Adams 1993, 342). However, besides grinding efficiency, grinding intensity should also be considered when trying to understand the aim of the changes seen in the grinding tools. In this sense, efficiency could imply the same or less time spent in feeding more or the same amount of people. More intensity requires more time grinding, either to feed more people or to increase production, though this variable is harder to measure (Wright, M. 1993).

Babot (2006), following previous research, states that the efficiency of grinding is related mainly to the surface area of the artefacts: therefore, the bigger the area, the more time is saved, however, this also requires more effort in the processing being a limit for the efficiency of the artefacts, hence becoming relevant the intensity on grinding or the time invest in this activity (Babot 2006, 80). Babot (2004; 2006) has widely investigated the grinding technology using morpho-technological and residue analyses. She had worked on puna, pre-puna and valleys in the provinces of Catamarca and Tucuman, Argentina, in a time span from 9700BP until modern times. The grinding technology in Northwestern Argentina appears only around 6400BP with *manos* and in 5400BP with morteros and conanas. This technology shows up during a period of low humidity in which occupations are settled on areas with pastures and water. In this context, she proposes that “the first grinding artefacts implied a new technology in a situation of diet expansion” (Babot 2006, 85).

In the Levant, the transition to farming (11500-9600BP) was characterised by rising frequencies of grinding tools relative to pounding tools (Wright 1994). The author suggests that this strategy is an attempt to “maximise nutritional returns of plants harvested from the limited territories characteristic of sedentary foraging and early farming” (Wright 1994, 238). Maximisation would have been given by caloric return per unit of area rather than per unit of time. She links this necessity of intensification to the Younger Dryas, when storability diminished processing costs. In this sense, grinding also increases storability. Stored foods are vulnerable to loss. Therefore, the risk of loss can be reduced by pre-treatments that inhibit seed germination or other factors. However, Wright *et al.* (2008) also found that sandstone grinding slabs might be related to finer abrasion of beads and this is extremely interesting for Atacama, due to the rise in bead production during the Formative period.

Ethnographic and archaeological data make it difficult to assume that specific ground-stone tool types correlate with specific foods (Wright 1994) and functions (Liu *et al.* 2011). Different plants can be expected to be processed in different forms. For instance, oily seeds are easier to process on flat surfaces, as they stick to them, avoiding loss (Adams 1999; Wright 1994). Also it is accepted that those with deep and conical cavities are more suitable to crush or pound compared to grinding of the flat ones (Wright 1992). On the other hand, grinding creates finer, more homogeneous particles than does pounding, permitting better bioaccessibility (Stahl 1989; Wollstonecroft *et al.* 2008; Wright, K. 1993; Wright 1994).

So even if processing is seen as a cost in resource exploitation, it can affect positively the nutritional qualities of food. Thus a resource can be processed in numerous ways, resulting in different payoffs (Stahl 1989, 171). In this sense, plant food processing provides a potential avenue for intensification that is independent of resource change (Stahl 1989). Also the processing of resources such as *Prosopis* and *Geoffroea* could facilitate their transportation and conservation (Núñez *et al.* 2006), diminishing the useless weight and allowing deferred consumption (Jackson & Benavente 2010).

It has not been possible to identify a precise origin for the introduction of flat mortars, although it might have begun as part of the increasing interaction with neighbouring areas, either as an idea or with the arrival of new populations. In fact, this morphology was already present in the Las Pircas Phase (9800-7800BP) of Northwestern Peru (Rossen 2011). In Chiripa in the Early Formative period (3450-2950BP), Hastorf (2003) has described flat grinding stones as part of the offerings in a female burial, the same pattern shown in Tulan 54 newborn burials. In Northwestern Argentina, flat grinding stones are appearing by 5400 to 3250BP, so rather earlier than and coetaneous to the dates in Atacama (Babot 2006). For Atacama, “Guevara says that the stone for grinding toasted corn, flat and semicircular in shape, was probably imported from the cultural centres of the north” (Timothy 1961, 26).

Therefore is it necessary to ask why new processing technologies were adopted. What were the communities looking for with this technological change – increased production, the processing of new materials (e.g. crops, wild plants, or inorganic materials), more free time, more available calories, new flavours, or did it reflect an adoption or imposition of a foreign cultural tradition?

Lithic hoes

Hoes also appear for the first time during the Early Formative period and have been considered as diagnostic of this phase (Figure 14 and 15). They have been found in cemetery contexts such as Chorrillos and permanent sites such as Chiu-Chiu-200 and 273 (Benavente 1978; Thomas *et al.* 2002); Vega Alta I, increasing in Vega Alta II (Pollard 1971), and in the Salar de Atacama in Tulan 122, Tulan 55, Tulan 67, as well as later in Tulor 1 (Barón 1986; Llagostera *et al.* 1984) and Calar (Orellana 1988-1989). In Topater, wooden hoes have been found (Thomas *et al.* 1995). The presence of these instruments is rare but significant, and thought to be related to early horticulture (Agüero 2005; González & Westfall 2006; Núñez 1995; Núñez *et al.* 2009). However, some scholars have suggested that these blades may correspond with mining (Núñez 1992) or other activities related to soil removal (Tamblay 1990). No accurate descriptions have been provided for this technology and its diversity within the area. Pollard (1971) describes “Ovoid and trapezoidal tubular porphyritic rocks, bifacially flaked on the edge. These are believed to have been hafted as hoe blades” (Pollard 1971, 44-45). Some ethnographic instruments give an indication of how they were used.

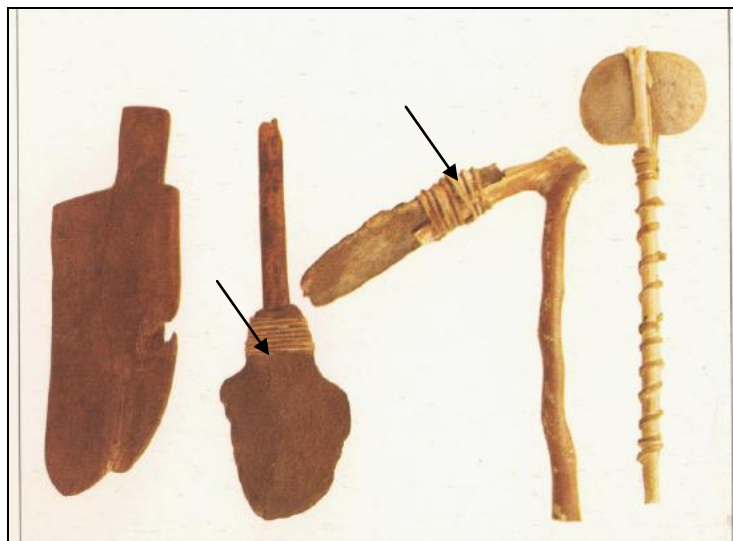


Figure 14. Ethnographic hoes in the San Pedro oases. Reproduced from Bittman et al. (1978, 49).

In Chorrillos cemetery the archaeological findings illustrate how these tools were arranged for use:

Figure 15. Lithic hoe offered in a tomb of Chorrillos. Below the blade, wood remains suggest a handle stick (courtesy of F. Martinez).

Therefore, these tools can be roughly described as lithic blades which were probably attached to a wooden handle when in use either by leather or vegetal straw.

If these instruments were used for tasks such as preparing the soil before and after cultivation (Hidalgo 2004; Latcham 1936b), they may have microfossils of crops attached to their fissures. Since soil retains microfossils of plants growing in it, the blades might incorporate some of them, or during the harvesting the blade can cut starchy organs, as might be the case with the tuber-type starch grain found in Tulan 55 (McRostie 2007) (Figure 16).



Figure 16. Starch grain found on lithic hoe Tulan 55 estrato 3. Reproduced from McRostie (2007, 47).

In the Western valleys of the northern Coast of Chile, lithic hoes are also present in the Formative sites of Ramaditas and Guatancondo (Rivera *et al.* 1995-1996). In the Puna de Jujuy, similar hoes have been found in graves (Latcham 1936b, 320). In north western Argentina, they are abundant in contexts of food production economies and have been related with agricultural practices, although other activities related to cleaning practices of campsites and digging pits for storage of products are also suggested (Haber & Gastaldi 2006; Pérez 2010). Dillehay (2011) reports wasted hoes in the north-western valleys of Peru since the Las Pircas Phase (9800-7800BP). These have been mainly found in horticultural residences with gardens (Dillehay 2011, 39). During the Early Formative (3550-2750BP) of the Titicaca basin small quantities of hoes have been found, whilst during the Middle Formative (2750-2200BP) hoes quartzite and andasite rise; becoming notorious during the Late Formative (2200-1450BP) (Bandy 2001). Capriles *et al.* (2011) reports the appearance of hoes in the northeast margin of the Uru-Uru lake during the Formative period (3500-1600BP). They relate this new technology with the development of new economic activities such as agriculture. Bandy (2001) considers that the basalt hoes during the Chiripa phases reflect the strong focus on agriculture. So do others authors working in the Titicaca area (Fox 2007; McAndrews 1998), though these tools could have been used either for agriculture or for extracting wild resources such as totora or simply digging. The

construction of large semi-subterranean structures and pottery production would certainly require effective digging implements (Whitehead 2006, 272).

Irrigation systems and farm lands

So far the archaeological record has not provided early evidence of irrigation systems or farm fields. Nevertheless, a typology for irrigation systems made by Santoro *et al.* (1998), based on later periods of the Atacama and Tarapaca valleys, allows us to consider three irrigation systems:

1. Drainage canal: simple canalisation of excedentary waters, usually abandoned after the resource is consumed. This strategy usually is accompanied by optimal weather conditions and the uptake of the nutrients brought by the flood allows a high yield per cultivated surface.
2. Conduction canal: Complex canals that conduct permanent water through steep slopes. They usually require stone architecture and soil movements to make terraces.
3. Aqueducts: Highly complex system used to bring water from one valley to another.

The authors suppose that, from an evolutionary perspective, the drain canals were the earliest means of water management. Indeed, this is the system that has been argued to be used in Tular 1 village and other Formative sites, supporting early maize agriculture (Agüero 2005; Barón 1986; Llagostera *et al.* 1984; Núñez 1974; 1982; 1995; 2005). In later times, around 1550-1250BP, the spread of archaeological sites within the deltas of the San Pedro and Vilama rivers, induced researchers to think that a more effective use of water was being executed by canals (Llagostera & Costa 1999). Núñez (1995) proposes an earlier date for the first irrigation (3450-2950BP) in the ravines and then around 2550-2350BP to a more sophisticated system of canals in the oases (Núñez 1995, 35). However, Castro *et al.* (2004) state that is not until after 1200BP that the use of agro hydraulic paleo-technologies expanded. Then, with the Incas, agricultural activity grew markedly in the large fields of terraces in the ravine zone, as exemplified in Socaire, Toconce and Paniri.

Concerning the farm fields, it has been argued that because the first horticulture or agriculture was conceived as using temporary drainage canals, the evidence would have

been washed away or is buried under meters of soil and sand (Núñez 1995). However, different types of fields dating from pre-Inca times are described for the area: andenerias, terrazas and melgas (Santoro *et al.* 1998). The former were mainly built in the mountain slopes or river terraces, whilst the latter have been reported in the oases of San Pedro in Tulor, Beter, Poconche and Cucuter. Melgas are described as depressed cultivated lands where canals of around 25 cms are undermined, accumulating the soil at the edge of each so that water can flow through that path. These still were used in the 20th century, although they date from pre-hispanic times due to their association with pottery and lithic materials, though no hoes have been reported. Usually in the desert areas the soil was fertilised with dung from camelids and decomposed leaves, whilst on the coast, bird dung and fish bones were also used (Gundermann & González 1995; Latcham 1936b; Ravines 1978).

Storage

One characteristic of Andean culture is to maintain and accumulate production for as long as possible, not just to avoid risk during food shortages or winter seasons and to maintain seed for the next planting, but also to be able to have access to a diverse range of products produced in other areas through the different mechanisms of access and interchange proposed for the southern Andes and the Atacama. There is limited information about storage structures in Atacama. During the XVI century, Bibar (1966 [1558], cited in Zapater 1976-77), describes that the Indians of Atacama had mud houses which have above containers and also made some small rounded mud structures where they kept their foods: maize, potatoes, beans, quinoa, algarroba and chañar. Assumptions of archaeological storage facilities have been made from architectural patterns (Adán & Urbina 2007; Agüero 2005; Latcham 1936a; Llagostera *et al.* 1984; Núñez 1992). For instance, Latcham describes that “all the buildings had a granary or store room, sometimes two; almost always inside the larger room, but occasionally outside adjoining one of the walls. They were built of stone, about four feet high, with no doors, but near the ground a square opening of the same size, shape, and construction as the windows. It is probable that these granaries were roofed, as we frequently found remains of sticks and rushes in the interiors. In a good many of the houses, especially in the upper part, near the southern end of the city, we also found

underground granaries, sometimes lined with stone slabs, and the entrance covered with a larger one. Many of these had been used as sepulchres and contained one, two, or more skeletons” (Latcham 1936a, 53-54), translated by V.McRostie). Núñez (1998) describes for Peine that maize is dehusked and dried in granaries before being stored in sacks. Chañar and algarrobo are also gathered after they fall from the trees, and once dried, they are stored in sacks. These products are then used by the community, for their animals and for trade. Other relevant data is the appearance of pottery urns that could be used for storage during the Early Formative (Berenguer *et al.* 1986; Tarragó 1968) and their continuity throughout the pre-Columbian sequence.

In ancient Peru, two types of deposits existed for storage: *collicas* (state) and *pirwas* (domestic). The latter could be inside the houses, made from light materials (cane, totora), above the roof or underground in mud, soil or sand deposits. The products could be put in wool bags or vessels covered with mud. Sometimes different plants were used to keep away insects (Ravines 1978). Preservation methods were based on local geography, but it seems that there are four main categories of food conservation (Ravines 1978). These methods have been described widely in Andean literature and they are dehydration; toasting and flour, which reduce the weight and volume of the product, rendering it longer lasting and more suitable for transportation. Fermentation is described by Stahl (1989) as a conservation practice, though chicha rapidly becomes vinegar when left from one day to another (Muelle 1978, cited in Pardo & Pizarro 2005).

P e r i o d	A r e a	Eco- syste m	Phas e	Site	BC-AD BP	Site type	Grindin g tools	H o e s	Crops	Wild plants	References
LATE ARCHAIC	L o a	river	Chiu Chiu	Kalina	2420- 2000B C 4370- 3950B P	Semi	conical mortar s and manos	N o	No	No	Aldunate et al 1986
	SALAR DE ATACAMA	river	Chiu Chiu	Ghatch i 2C	4000- 3450B C 5950- 5400B P	Semi	conical mortar s and manos	N o	No	Cactus, Scirpus	Agüero 2005; Agüero et al 2009; Vidal 2007
		ravin es	Chiu Chiu	Tulan 52	2390- 1930B C	Semi	conical mortar s and manos	N o	Lagenaria sp.	Prosopis, Geoffroea, Scirpus, Cactus, various	McRostie 2007; Núñez 1986-87; Núñez et al 1995; 1999; Núñez 2005; Núñez et al 2006; 2009
		river	Chiu Chiu	Puripic a 1	2340- 2100B C 4290- 4050B P	Semi	conical mortar s and manos	N o	No	No	Núñez 1981b; Núñez et al 1995; 1999; Núñez and Santoro 1988
EARLY FORMATIVE	L o a	oases	Vega Alta I	Chiu Chiu 200, Chorrill os	910- 190BC 2860- 2140B P	semi- cem	Flat, conical mortar s and manos	Y e s	Zea mays, Lagenaria sp., Gossipium, Chenopodium sp.	Prosopis, Geoffroea, various	Belmar and Quiroz 2005; Benavente 1982; 1988-89; González and Westfall 2006
	SALAR DE ATACAMA	river	E.F	Gatchi	350BC- 100AD 2300- 1850B P 2330- 1750B P	Perm	flat mortar s and manos	Y e s	Cf. Chenopodium	Scirpus, various	Agüero 2005; Agüero et al 2009; Vidal 2007
		ravin es	Tiloc alar	Tulan 54, 55, 58, 67, 122	1400- 400BC 3350- 2350B P	semi- perm - ritual -cem	flat mortar s and manos	Y e s	Cf. Chenopodium, Zea mays, Cucurbitaceae	Prosopis, Geoffroea, Cactus, Scirpus, tuber various	McRostie 2007; Núñez 1986-87; Núñez et al 1995; 1999; Núñez 2005; Núñez et al 2006; 2009
		mead ows salar	Tiloc alar	Tulan 85	1400- 400BC 3350- 2350B P	Semi - perm -	Conical , flat mortar s and manos	N o	Zea mays Lagenaria sp.	Prosopis, Geoffroea, Scirpus, Cactus, various	McRostie 2007; Núñez 1986-87; Núñez et al 1995; 1999; Núñez 2005; Núñez et al 2006; 2009
	L o a	river	Vega Alta II	Ranl 273, Chorrill os	200BC	perm -cem	flat mortar s and manos	Y e s	Lagenaria sp, Chenopodium sp.	Prosopis, Scirpus, cactus, various	Belmar and Quiroz 2005; González and Westfall 2005; Pollard 1971
LATE FORMATIVE	ATA CAMA	oases	Toco nao	Tocona o	350BC- 100AD 2150- 1850B	Cem	Manos	N o	Lagenaria sp.	Prosopis	Tarragó 1984; Vidal 2007

				P						
	oases	Tocoma	Tulor 1	380±65 BC 200AD	Perm	flat mortars and manos	Yes	Zea mays, Lagenaria sp.	Prosopis, Geoffroea	Barón 1986; Llagostera et al 1984; Vidal 2007
	ravines	L.F.	Tulan 57, 59, 71, 109	400BC-500AD 2450-1450B P	Perm	Flat and conical mortars and manos	Yes	Zea mays, Cucurbitaceae, Gossypium	Geoffroea, Prosopis, Opuntia	McRostie 2007; Núñez 1986-87; Núñez et al 1995; 1999; Núñez 2005; Núñez et al 2006; 2009
	meadows	L.F.	Tulan 82, 85	400BC-500AD 2450-1450B P	Semi-perm	Flat mortar and manos	Yes	Zea mays, Lagenaria	Prosopis, Geoffroea	McRostie 2007; Núñez 1986-87; Núñez et al 1995; 1999; Núñez 2005; Núñez et al 2006; 2009
	river	L.F.	Calar	200BC-346AD 2150-1605B P	Semi-perm	Conical mortars	Yes	Lagenaria	Prosopis, Geoffroea, cactus	Orellana 1988-89; Vidal 2007
	river	L.F.	Puripica 23, 31	190-80AD 1770B P	perm	flat mortars and manos	Yes	Zea mays	Prosopis, Geoffroea	Núñez et al 1995-96; 1999

Table 21. Main sites, phases, ecosystems, technologies and crops (L.A: Late Archaic, E.F: Early Formative, L.F: Late Formative; semi: semi-permanent, cem: cemetery, perm: permanent).

V.3 Animals in subsistence

In the Atacama, both wild and domestic animals were consumed by humans. The most relevant species for humans were wild and domestic camelids. These were determinant in the cultural development and subsistence of Andean populations. Also relevant to diet consumption were small mammals such as rodents, birds and their eggs.

However secondary products such as skin, furs, dung, fat and bones as well as the role of camelids in transport and the ritual connotations of these animals, will not be considered further in this short review.

Zooarchaeological data

The breeding and hunting of camelids was decisive for human survival and cultural development in the Andes. These animals provided humans with wool, fur, meat, excrement - used both as fuel and fertiliser - and of most importance, the llama as a beast of

burden allowed the possibility of establishing a caravan system, which supported extensive and complementary networks through all the Andes.

Domestication of camelids seems to have occurred multiple times, with the initial appearance of the llama around 4400-3000BP, with a continuous intensification around 3000 to 2000BP, such as the development of more specialised uses of in textile production (Mengoni & Yacobaccio 2006). In the Loa and Salar regions, the Atacama local domestication during the Late Archaic period is a well-supported hypothesis (Cartajena 1994; 1995; Cartajena *et al.* 2003; Cartajena *et al.* 2007; Hesse 1982b; Yacobaccio 2003). The abundance of small camelids' bones and vicugna fibres in samples from the Late Archaic and Formative sites in Atacama (Puripica and Tulan) denotes the relevance of hunting practices. Alpaca was not identified, and big bones are associated with the guanaco and llama. In the Middle Loa, the presence of llama has been documented around 3000BP-2000BP (Benavente 1982; 1988-1989; Cartajena 1994; Pollard 1971). At the base camp of Chiu Chiu cemetery (5300-3000BP), guanaco and llama fibres were identified (Cartajena 1994). In Chorrillos, at least five large specimens were identified (llama-guanaco). Only one offering of a camelid leg was identified as *Lama glama* (González & Westfall 2006).

In Tumor 1 there is no accurate identification of taxa among the camelids, even though they compose 100% of the sample. In the corral areas (sector 7) the sizes were bigger than in the village structures (Barón 1986). Analyses of yarns and fleeces in Quebrada Tulan (Tulan 54) by Dransart (1991; 2002) reveal domestic camelids by 3100BP, increasing by 2600BP. It seems that herders' societies would keep on hunting guanaco and vicuña, the former for their meat and the latter for their fibre, whilst the llama would have mainly a burden role (Cartajena 1994; Cartajena *et al.* 2007; Wheeler *et al.* 1977).

Other animals that were less important in subsistence (diet and fur) are rodents, which can be classified as major rodents (chinchilla - *Chinchilla laniger*-, vizcacha -*Lagidium viscacha*- and cholulo -*Ctenomys fulvus*-) and minor rodents (the chinchilla mouse and Sigmodontinos). The major rodents have been recorded as having undergone cultural exploitation in Late Archaic and Early Formative sites in Tulan, with *Chinchilla laniger* gaining special relevance. This would reflect the relevance of secondary products in a context of increasing interaction and requirement of wealth trades (Labarca 2005).

Birds seem to have this same role in Tulan in terms of secondary products (Labarca 2005), as well as during the Early Formative period in the Loa region (Arias *et al.* 1991; Benavente 1981). Scarce remains predominate in the Late Archaic and Formative sites (Hesse 1984). It is hard to discriminate whether taphonomical variables created this pattern, or if indeed they are scarcely exploited by the communities. Also, the causes surrounding the deposition of small rodents in archaeological sites are not always clear and could be due to cultural or natural variables (Hesse 1984).

V.4 Bio-anthropological data

Kilocalorie estimations for Atacama

To have a better understanding of the foods and their potential values in the Atacama diet, as well as their significance for subsistence strategies, I shall refer to the expected consumption patterns of the Atacama population. Relying on archaeological and ethnographic information, we could hypothesise that communities that inhabitant the area based their diet on camelids, small mammals and wild plants like protein-rich *Prosopis* sp. pods and *Geoffroea decorticans*, as well as other wild plants such as *Scirpus* sp. rhizomes and cactus fruits (*Opuntia* sp., *Echinopsis* sp.) and seek to assess when crops such as maize, tubers and pseudocereals began to play a significant role in local subsistence.

Most of archaeological techniques do not permit an accurate assessment of the exact percentage that each element contributed to diet, although differences between primary diet and occasional use may be made. Similarly, although the consumption of different foods is likely to have varied in relation to age, gender and status as well as seasonal and ecological factors the nuances of this cannot be explored within my methodology. In this section I will discuss general models for the broad human nutritional requirements of hunter-gatherers, as well as the kilocalories that local resources can provide. In later chapters this will be used to assess the significance of the archaeological evidence for subsistence patterns according to period and the degree to which there are regional variations within the Atacama study area.

Analyses of hunter-gatherer diets assume caloric intakes of approximately 3000kcal/day (Cordain *et al.* 2000). Daily nutritional requirements can be divided into calories and nutrients (carbohydrates, proteins and fats), which give the required daily caloric input per individual (Table 22). According to Palaeolithic hunter-gatherer models (Eaton *et al.* 1997; Eaton *et al.* 1996; Eaton & Konner 1985), these proportions can be divided into:

<i>Based on 3000 kilocalories</i>	<i>Daily amount calories (range)</i>
<i>Proteins (37%)</i>	<i>1110</i>
<i>Carbohydrates (41%)</i>	<i>1230</i>
<i>Fats (22%)</i>	<i>660</i>

Table 22. Daily caloric requirements per individual based on Palaeolithic models.

Whether these values are obtained from plants or animals is not easy to estimate when relying on available local data, though other studies can give us some insights to enable us to start exploring this issue. Cordain *et al.* (2000) estimated macronutrient intakes (% of energy) for environmentally diverse hunter-gatherer populations, based on an ethnographic compilation of plant to animal ratios within economic subsistence patterns (Murdock 1967). They analysed the economic subsistence data for 229 hunter-gatherer societies using three subsistence categories (gathered plant foods, hunted animal foods, and fished animal foods). From these data, they concluded that most (73%) hunter-gatherer societies derived >50% of their calories from meat (including wild game and fished foods), while only 14% of societies derived >50% of their calories from plants, although the variability in the plant: animal ratio was very high depending on latitude, climate, location and seasonal variations. Of particular relevance to this study is the fact that hunter-gatherer groups who lived in the desert grasses and shrubs (n = 11) relied 46–55% on gathered plant foods, 36–45% on hunted animals and 6–15% on fished animals. Also *Acacia* seeds represented the higher energy density values among the gathered plants. Another important statement to consider is that in hot desert environments, very high protein intakes are undesirable. “If present in sufficient quantities, the traditional diet of West Asia, based on low-protein cereal grains and protein-rich leguminous seeds and featuring tea and coffee while excluding alcohol, fulfils most theoretical criteria for an appropriate diet in deserts” (Seely *et al.* 2006, 28). High protein diets in the deserts are undesirable because they increase water requirements, but this would especially apply to meat. High protein intake replacing dietary carbohydrate

results in increased need for protein as a source of glucose, and increased conversion of amino acids to glucose. “Deamination of amino acids increases ammonia and sulfuric acid generation, which the body must dilute with water and excrete in urine (ammonia as urea, sulfuric acid as acid)” (D. Matesz pers. comm. 2013).

Optimisation models used in the Argentinian Puna Salada for hunter-gatherers consider that an optimal diet was firstly based on camelids, then on small rodents and animals and afterwards on tubers, seeds, fruits and herbs (Muscio 1999; Olivera 1998; Pintar 2008; Yacobaccio 2004; 2007).

Camelids are large, ecologically dominant and predictable herbivores, and therefore their hunting and domestication is an efficient strategy to obtain high amounts of proteins and fats (Mondini & Elkin 2006; Muscio 1999; Olivera 1998). Additionally, the abundance in the landscape of the “sub-optimal” resources can turn them into high ranked items, such as, for example, suri eggs in the Puna, which are encountered in quantities of 8 to 25 per nest and are highly visible and predictable (Muscio 1999).

Nevertheless, these models do not include Legume trees available in the western Atacama Puna. Cordain *et al.* (2000) and Seely *et al.* (2006) state that plant resources such as Legume trees are highly ranked in some environments. In this sense, Milton (2000) argues that just because some hunter-gatherer societies obtained most of their dietary energy from wild animal fat and protein, this does not imply that this is the ideal diet for modern humans (Milton 2000, 666). She cites several examples worldwide in which diets are more dependent on plants when these are rich in kilocalories, even if large prey animals are available.

For instance, *Prosopis alba* is expected to produce up to 100 kg of pods per mature tree and *Prosopis chilensis* between 10kg and 200kg (Galera 2000). This productivity varies seasonally and annually, though dry and arid environments favour pod production (Llano *et al.* 2012). The oil in chañar fruits is high (47.2%) and is comparable to commercial oily seeds such as peanuts (38-50%), rapeseed (40-60%) and sunflower (20-32%). It is also a good source of protein, comparable in quantity to other oil seeds (Lamarque *et al.* 2000). Llano and Ugan (2009) measured the kilocalories of *Prosopis* and *Opuntia* (among other plants which do not

grow in Atacama), including the energy invested in grinding, and when considering their value as fruits without processing, *Prosopis* was in the highest ranking, though when considering their return after grinding in morteros and conanas, this return diminished, especially with the conanas (conanas: 567kcal versus morteros: 970kcal). This brackets *Prosopis* grinding in conanas with maize agriculture in terms of costs/benefits. In another paper Llano *et al.* (2012) give the nutritional values for *Prosopis* pods (1.3–3.5% fats; 9-17% proteins and 40-50% carbohydrates). The raw fibre of the pods is low (an average of 12gms per 100gms), making them highly digestible for humans. The nutrient value of *Prosopis* varies according to the processed part. Carbohydrates are higher in the epicarp and mesocarp and hence in the first stage of grinding. These values diminish in the endocarp (second stage of grinding) and finally the breakout of the seeds, where the protein is incorporated, returns a low value of sugars and the cost of this grinding results in a low return of kilocalories per energy invested, and hence this third stage is usually abandoned in order to start with a new set of pods (Llano *et al.* 2012). However, *Prosopis* pods production and nutritional content varies greatly between species, growing location and climate conditions (Beresford Jones 2011).

Below I will present a table with kilocalories available per edible resource documented in the Atacama area, based on values from different sources, as there is no local baseline (Table 23). However, with the information currently available, I cannot model a specific diet for the archaeological populations studied and the information will be used as a general guide to discuss changes in resources.

PLANT	PLANT PART	KILOCALORIES VALUE PER:	X grms	KILOCALORIES per 100 grms	REFERENCE
Suri eggs		11.850(post-finding)	0.6kgs	1975	Muscio 1999
Tubers		16.625(post-finding)	1kgs	1662	Muscio 1999
Puna Fruits		8.000(post-finding)	1kg	800	Muscio 1999
Birds		6.916(post-finding)	0.91kgs	760	Muscio 1999
Vizcacha		8.108(post-finding)	1.2kgs	675	Muscio 1999
Zea mays	Kernels (flour)	110	31grms	370	Quaker product
Prosopis sp.	Legume pod (flour)	332.31	100grms	332	Charpentier 1998, cited in Figueroa and Dantas 2006
Geoffroea decorticans	Fruit (flour)	320.84	100grms	320	Charpentier 1998, cited in Figueroa and Dantas 2006
Bolboschoenus maritimus	Seeds	3.8-4.3	1gram	380-430	Wollstonecroft and Erkal 2003
Bolboschoenus maritimus	rhizomes	4.6	1gram	460	Wollstonecroft and Erkal 2003
Chenopodium sp.	Small fruit	195	100grms	195	Sobolik 1991, cited in Riley 2010
Suri meat		24.700(post-finding)	13kgs	190	Muscio 1999
Puna Herbs		1.750(post-finding)	1kg	175	Muscio 1999
Ombrophytum subterraneum	Tuber	126	100grms	126	Pardo 2010
Taruca		36.250(post-finding)	29kgs	125	Muscio 1999
Vicuña		32.400(post-finding)	27kgs	120	Muscio 1999
Guanaco		32.400(post-finding)	42kgs	77	Muscio 1999
Puna Seeds		323(post-finding)	1kg	32	Muscio 1999
Opuntia sp.	Fruit	41	100grms	41	USDA 2006, cited in Riley 2010
Opuntia sp.	Cladode	27	100grms	27	Sobolik 1991 in Riley 2010

Table 23. Kilocalories from main edible resources based on different references (from highest to lowest).

Osteological, tooth wear analyses and coprolites

Another class of evidence that can provide information about plant food ways is bio-anthropological data. Bio-anthropological studies conducted on Formative populations from the oases allow us to appreciate nutritional variables. Compared skeletal data from the Late Formative cemetery Solcor 3 (1700-41470BP) and the Tiwanaku period (1450-1050BP) reveal that during this latter period, there was a significant increase in adult stature in the region (Neves & Costa 1998). Also a lower occurrence of caries, occlusal abrasion and loss of teeth could be reflecting either an increase in the consumption of animal meat or a lower effort in mastication due to techniques related to pre-oral preparation (Costa *et al.* 2004).

Major access to meat during the Tiwanaku period might be possible due to intensification in herding or because San Pedro served as a distribution point where an intense traffic of caravans allowed Atacameños to shift their own camelids from transport to food items. For the authors, this latter hypothesis is more accurate due to the natural limitations of the oases to intensify herding.

From these analyses, we can only derive a relative notion about the Formative diet. In this sense, other analyses allow us to confirm the idea of a Formative diet with a strong carbohydrate plant component. Agüero (2005) states that in the oases during the Late Formative, the tooth wear shows the consumption of un-sieved flour (Agüero 2005). In Chorrillos cemetery, tooth wear and osteological analyses (Reyes 2005) established that people were consuming a “soft diet”, composed mainly of ground plants with a high proportion of carbohydrates (e.g. maize, chañar, algarrobo), although the crown wear shows a para-functional use and the incorporation of hard products in the diet such as meat, fibrous and abrasive plants. The general conditions of the individuals lead to infer that the new sedentary and agricultural lifestyle brought more food security but also major infections, which weaken the individual, not allowing assimilation of all nutrients (Reyes 2005).

Holden (1991) analysed two samples of gut material from mummies present in Tulan 58 (2240-50BP) and twenty-eight human coprolites from the related site Tulan 54 (3000BP). The results showed that both small and large animals were eaten regularly and that plant remains were dominated by cactus seeds (*Opuntia* sp.) and the starchy underground storage organs of a rush identified as *Schoenoplectus americanus* (unquillo). The proportion of cactus seeds was estimated at around 25%, whilst for the rush rhizomes, it was around 7-10%, by weight of dried, unprocessed resource (Holden 1991, 79). Both species grow in the surrounding area. Low quantities of *Chenopodium* sp. and rocket-type seeds (*Sisymbrium* sp.) were also present, as were other local seeds. Animal remains such as bone, feather and hair were also found.

Isotopes

-Carbon and Nitrogen

General principles and methodology of isotope analyses have been widely explained in several articles (Ambrose 1990; Barberena 2002; Bentley 2006; Knudson et al. 2004; Tykot 2004; Tykot et al. 2009). A brief summary of the methodology for analysing of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, and the need for local comparative material, will be described in chapter VII. Basically, the broad assumption is that the composition of human (and animal) bone is dependent on what the individual has been eating, and that the consumption of C4 plants particularly maize will result in bones that have a $\delta^{13}\text{C}$ value of -12.5‰ -13‰ whereas the consumption of C3 plants (which includes most other plants consumed in the Andes) produces average $\delta^{13}\text{C}$ values around -26‰ -27‰. On the other hand $\delta^{15}\text{N}$ allows to measure protein source and trophic level. Human consumers of terrestrial plants and animals usually have a $\delta^{15}\text{N}$ in bone collagen of 6-10‰, whilst a diet based on marine or lacustrine resources has a $\delta^{15}\text{N}$ of 10-20‰.

Here I review previous studies in the region that have used this analytical approach (see Figure 12 and CH. III for location of sites and localities). Stable isotopes for diet determination ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) have been examined in the area by some preliminary analyses done in 1. the Formative Chorrillos cemetery (González & Westfall 2006), 2. during the Late Intermediate period (1100-1400BP) in Caspana (Knudson & Torres-Rouff 2009), 3. and 4. during the Middle Formative (2450-1850BP) in the San Salvador River, a tributary of the Loa river (Knudson *et al.* 2012; Torres-Rouff *et al.* 2012).

In the first analysis, two individuals from the Formative Chorrillos cemetery (2800-2140BP) have $\delta^{15}\text{N}$ values of 14.7‰ and 10.7‰. The authors consider that the former indicates a moderate ingestion of marine products, especially molluscs, while the second individual only consumed marine resources as a supplement to a broader plant and meat diet (González & Westfall 2006, 7). In the second study, Knudson & Torres-Rouff used $\delta^{13}\text{C}_{\text{ap}}$ in tooth enamel and here the signature (with a mean value of -6.7) reflects a mix of predominantly C4 with smaller amounts of C3 carbon sources. While this could reflect an addition of marine diet, the zoo-archaeological data and the strontium isotopes do not support this hypothesis (Knudson & Torres-Rouff 2009). Therefore $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}_{\text{col}}$ should be realised to reaffirm this. In the third study, analyses of $\delta^{13}\text{C}_{\text{ap}}$, $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$ from seventeen individuals of the San Salvador cemetery gave a range $\delta^{13}\text{C}_{\text{ap}}$ of -14.3‰ to -9.4‰. In this

example the lower value suggests the consumption of purely C3 plants, whilst the highest could have consumed up to 40% of CAM/C4 plants. The $\delta^{13}\text{C}_{\text{col}}$ average was -16.8‰ with a range from -15.5‰ to -18.8‰ , whereas the calculated $\Delta^{13}\text{C}_{\text{ap-co}}$ values average 5.9‰ and range from 4.2‰ to 7.9‰ . These values suggest the consumption of local terrestrial fauna and the enriched $\delta^{13}\text{C}$ signatures reflects regional freshwater fish and marine taxa. That the spacing values average around 5‰ , which probably attests to the fact that dietary proteins, like the dietary carbohydrates, were drawn from multiple, isotopically distinct reservoirs (Torres-Rouff *et al.* 2012, 61). The $\delta^{15}\text{N}$ values above 12.5‰ suggest marine ingestion. They interpret these results as a population highly involved in exchange within the coast and the highlands. In the fourth and last study, (Knudson *et al.* 2012) analysed an adult male from the Late Formative period (1950–1450BP) found in a vast and uninhabited part of the hyper-arid Atacama Desert on a route connecting the northern Chilean Coast to the Loa River Valley. They reconstructed diet and mobility using stable carbon and nitrogen isotopic data from bone collagen and hair keratin, stable carbon and oxygen isotopic data from enamel and bone hydroxyapatite carbonate. Bone hydroxyapatite carbonate in this individual exhibited $\delta^{13}\text{C}_{\text{ap}}$ -8.6 to -10.6‰ , which is consistent with the consumption of mixed C3 and C4 plants, animals and/or marine resources. Highly enriched bone collagen nitrogen isotope data ($\delta^{15}\text{N}_{\text{col}}$ 21.6‰) indicates that he habitually consumed marine foodstuffs, particularly high-trophic level marine protein, over the last 10–30 years of his life. Enamel hydroxyapatite carbonate in this individual exhibited $\delta^{13}\text{C}_{\text{ap}}$ -7.4‰ , which is also consistent with the consumption of a mixture of C3, C4 and marine resources during the first years of life. Carbon isotope data from hair keratin were variable, and ranged from $\delta^{13}\text{C}_{\text{ker}}$ -16.5‰ to -12.3‰ . Similarly, nitrogen isotope data from hair keratin were variable, and ranged from $\delta^{15}\text{N}_{\text{ker}}$ 17.1‰ to $\delta^{15}\text{N}_{\text{ker}}$ 24.6‰ . Based on these data, the authors argue that this individual was moving over long distances between areas with different foods (inland/coast) through different times of his life.

A nearby area where stable isotope studies of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ have been conducted is in Pisagua, on the coast of the Atacama Desert (Aufderheide *et al.* 1994). Members of the Alto Ramirez cultural group (ca. 2950BP) were analysed to determine whether they acquired the marine subsistence practices or maintained their agricultural and pastoralist tradition from

the highlands and inner valleys. Samples of hair, soft tissue and bone were collected for isotope analyses. Isotopes of carbon, nitrogen and sulphur were analysed to identify and quantify food resources on diet. A brief baseline was built for the area, although an extensive baseline has been made for the northern Azapa valley (Tieszen & Chapman 1992; Tieszen & Fagre 1993).

Regarding the local baseline, some $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ vegetation studies have been made in the Atacama Desert (Table 24). $\delta^{15}\text{N}$ was analysed from leaves of dominant species along a fog zone gradient to evaluate the sources of nitrogen in the marine area (50-900masl). The common value was $\delta^{15}\text{N}$ 6-12‰ (Evans & Ehleringer 1994). Also in the Atacama desert, nitrogen-fixation plants such as *Prosopis alba* and *tamarugo* were measured, giving values that averaged $\delta^{15}\text{N}$ 0.3‰ and 0.4‰ respectively. Non-nitrogen fixing plants such as *Pluchea* and *Distichlis* averaged 7.2‰ and 6.7‰ (Ehleringer *et al.* 1992).

Kraus *et al.* (2001) analysed $\delta^{13}\text{C}$ discrimination on *Opuntia atacamensis*. These species presents a range of $\delta^{13}\text{C}$ -12.06‰ and -13.35‰. The authors conclude that this plant seems to be able to fix CO_2 via the C3 pathway (Kraus *et al.* 2001, 164).

Slightly further south, also in the desert of the Atacama Coast, (Ehleringer *et al.* 1998) measured $\delta^{13}\text{C}$ from leaves, concluding that most of the species had C3 photosynthesis (-19 to -28‰), most of them had -25‰ and -21‰ although there were several CAM (*Copiapoa* -12,5‰, *Deuterochonia* -13.4-13.8‰) and only one C4 (*Atriplex* -13.7‰ to -14.8‰). Also the carbon isotope ratios of the C3 plants were unusually high, even for species from arid ecosystems.

Quade *et al.* (2007), from a study conducted within three areas of the Central Atacama desert, determined that C3 plants dominate the flora except for some CAM and a few C4 plants such as *Atriplex mucronata* (-15.7‰), *Cistanthe* sp. (-16.4‰) and *Nolana* sp. in the coastal fog zone (below 600masl). In the eastern margin of the pre-puna zone, most of them were C3 except for the C4 shrub *Atriplex imbricata* (-15.0 -14.1‰). In the tolar zone (3200-4000masl), in contrast to the shrubs, which were all C3, summer grasses were commonly C4 (*Aristida adscensionis*, *Bouteloua simplex*, *Enneapogon devauxii*, and *Munroa decumbens*). In the highland area, *Festuca chrysophylla* (C3), *Deyeuxia* spp., and *Stipa frigida* (C3), as well

as sparse perennials and a few cushion plants such as *Azorella* and *Pycnophyllum*, dominate the area. *Opuntia* is scattered in the area, having a CAM value of -11.2‰. The average of all C3 plants is -23.1‰. This average is markedly higher than global average values of around -27‰ for C3 plants, and is consistent with the higher water-use efficiency displayed by desert C3 plants (Quade *et al.* 2007, 3778).

Latorre (2002) reports an increase in C3 plant content at 4400BP, as indicated by a $\delta^{13}\text{C}$ of -23.2‰. In contrast, the Late Holocene $\delta^{13}\text{C}$ record is characterised by higher isotopic values, indicating strong C4 and CAM plant influences in rodent diets. These values are correlated to the highest percentages of *Atriplex* and *Cistanthe* in cuticle samples, especially after 3500kaBP.

FAMILY	G/SPECIES	$\delta^{13}\text{C}$	$\delta^{13}\text{C} + 1.5$ industrial effect	$\delta^{15}\text{N}$	REFERENCE	PP
Asteraceae	<i>Artemisia copa</i>	-21.6	-20.1		Quade et al. 2007	C3
Asteraceae	<i>Doniophyton cf. Weddellii</i>	-27.9	-26.4		Quade et al. 2007	C3
Asteraceae	<i>Haplopappus rigidus</i>	-21.7	-20.2		Quade et al. 2007	C3
Asteraceae	<i>Parastrephia lepidophylla</i>	-20.66	-19.16		Quade et al. 2007	C3
Asteraceae	<i>Pluschea sp.</i>			7.2	Ehleringer et al. 1992	C3
Asteraceae	<i>Senecio aff. Nutans</i>	-22.77	-21.27		Quade et al. 2007	C3
Boraginaceae	<i>Phacelia cummingii</i>	-23.3	-21.8		Quade et al. 2007	C3
Cactaceae	<i>Opuntia sp.</i>	-11.2	-9.7		Quade et al. 2007	C4
Cactaceae	<i>Opuntia sp.</i>	-12.06	-10.56		Kraus et al. 2001	C4
Cactaceae	<i>Opuntia sp.</i>	-13.35	-11.85		Kraus et al. 2001	C4
Chenopoidaceae	<i>Atriplex imbricate</i>	-14.14	-12.64		Quade et al. 2007	C4
Chenopoidaceae	<i>Atriplex imbricate</i>	-15.2	-13.7		Quade et al. 2007	C4
Ephedraceae	<i>Ephedra sp.</i>	-22.1	-20.6		Quade et al. 2007	C3
Fabaceae	<i>Adesmia melanthes</i>	-21.8	-20.3		Quade et al. 2007	C3
Fabaceae	<i>Adesmia spinosissima</i>	-22.5	-21		Quade et al. 2007	C3
Fabaceae	<i>Lupinus</i>	-22.76	-21.26		Quade et al. 2007	C3
Fabaceae	<i>Prosopis alba</i>			0.3	Ehleringer et al. 1992	C3
Fabaceae	<i>Prosopis tamarugo</i>			0.4	Ehleringer et al. 1992	C3
Malvaceae	<i>Cristaria andicola</i>	-24.2	-22.7		Quade et al. 2007	C3
Poaceae	<i>Chuquiraga atacamensis</i>	-21.29	-19.79		Quade et al. 2007	C3
Poaceae	<i>Distichlis spicata</i>			6.7	Ehleringer et al. 1992	C3
Poaceae	<i>Stipa frigid</i>	-22.8	-21.3		Quade et al. 2007	C3
Poaceae	<i>Stipa/Festuca</i>	-24.59	-23.09		Quade et al. 2007	C3
Polimoneaceae	<i>Gilia crassifolia</i>	-23.3	-21.8		Quade et al. 2007	C3
Portulacaceae	<i>Cistanthe amaranthoides</i>	-21.3	-19.8		Quade et al. 2007	C3
Portulacaceae	<i>Cistanthe salsoloides</i>	-22.9	-21.4		Quade et al. 2007	C3
Solanaceae	<i>Baccharis tola</i>	-20.71	-19.21		Quade et al. 2007	C3
Solanaceae	<i>Fabiana denudate</i>	-21.51	-20.01		Quade et al. 2007	C3
Solanaceae	<i>Jaborosa parviflora</i>	-22.5	-21		Quade et al. 2007	C3
Solanaceae	<i>Reyesia parviflora</i>	-21.6	-20.1		Quade et al. 2007	C3
Verbenaceae	<i>Junellia seriphioides</i>	-20.38	-18.88		Quade et al. 2007	C3

Table 24. Reference guideline $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ Atacama plants.

Regarding local fauna, López (2010) analysed stable isotopes ($\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$) from eight archaeological camelids *Lama aff. guanicoe* and *Lama aff. glama* recovered in Tulan 54 and Tulan 85 Early Formative sites (ca. 3100-2400BP). The results indicate differences in the diets of the two species, explained by altitudinal and seasonal changes in vegetation as well as pastoral practices.

In Tulan 54, $\delta^{13}\text{C}_{\text{col}}$ values ranged between -12.58‰ and -16.35‰. This can be separated in *Lama glama* (-13.87±.02‰ and -15.43±.04‰) and *Lama guanicoe* (-12.58±.35‰ and -16.35±.73‰). In Tulan 85, $\delta^{13}\text{C}_{\text{col}}$ values ranged between -13.92‰ and -16.84‰. This can be separated in *Lama glama* (-13.92±.01‰ and -16.41±.07‰) and *Lama guanicoe* (-14.11±.08‰ and -16.84±.35‰). When compared with the $\delta^{13}\text{C}$ vegetation values for the area (Quade *et al.* 2007), the author considers the pure values extracted from the collagen and the “isotopic diet” = $\delta^{13}\text{C} + 5, 1\%$ (Table 25).

Sample	Size group	$\delta^{13}\text{C}$	Isotopic diet ($\delta^{13}\text{C} + 5, 1\%$)
Tu-54/N6	Big/Lama	-13,87	-18,97
Tu-54/N9	Big/Lama	-15,43	-20,53
Tu-85/N8	Big/Lama	-13,92	-19,02
Tu-85/N14	Big/Lama	-16,41	-21,51
Tu-54/N7	Big/Guanaco	-12,58	-17,68
Tu-54/N14	Big/Guanaco	-16,35	-21,45
Tu-85/N2	Big/Guanaco	-14,11	-19,21
Tu-85/N7	Big/Guanaco	-16,48	-21,94

Table 25. $\delta^{13}\text{C}_{\text{col}}$ values for Tulan camelids. Reproduced from López (2010, 132).

He concludes that both sites present C3/C4 values, though with a higher incidence of C3. The presence of C4 is interpreted either as the mobility and use of the talar belt for pasture where C4 plants are available during summer or as the introduction of maize stalks as fodder. In this sense, the values of Tulan camelids are higher than previously reported for the puna for llama and alpaca, whose average is $\delta^{13}\text{C}_{\text{col}} - 22\%$ (Tieszen & Chapman 1992); and Central Peru $\delta^{13}\text{C}_{\text{col}} - 20\%$ (Schoeninger & DeNiro 1984). However, Fernández & Panarello (1988-1990) report values of $\delta^{13}\text{C}_{\text{col}}$ of -20‰ but also values ranging between -14‰ and -16‰, which indicate that camelids consumed more C4 and sometimes even marine resources (Burger & Van der Merwe 1990; Finucane *et al.* 2006; Izeta *et al.* 2009). The values for $\delta^{15}\text{N}$ (13.31‰) in Tulan are higher in comparison with other samples of

camelids from the Andes Centro-Sur (Fernández & Panarello 1988-1990; Mengoni 2009; Yacobaccio *et al.* 2009). These are within the limits of what is expected for a terrestrial and marine diet (+1.9/10.0 and +11.7/22.9 respectively) (Barberena 2002).

-Strontium and Oxygen

Although not used to assess diet in this research, these isotopes can determinate migrations related to the Late Archaic and Formative changes. The two most common methods used to identify archaeological human residential mobility are strontium and oxygen isotope ratios in dental and skeletal elements that formed at different times in an individual's lifetime (Knudson & Torres-Rouff 2009, 474). However, studies done by Knudson (2009) from oxygen and strontium isotope data demonstrate that oxygen values are conditioned by a series of variables (humidity, elevation, temperature and latitude) that make them less appropriate for identifying the environmental zone from which an individual came. In fact, more internal variability was found within than between sites even when $^{87}\text{Sr}/^{86}\text{Sr}$ isotopes were similar. Knudson and Torres-Rouff (2009) used oxygen isotopes in Caspana during the Late Intermediate period (1100-1400BP) to determine cultural heterogeneity. Samples were obtained from the apatite of different large bones ranging from $\delta^{18}\text{O}$ (VPDB) -2.9‰ to -4.9‰, with mean enamel $\delta^{18}\text{O}$ (VPDB) -3.8‰, ± 0.6 ‰. At the Middle Horizon (1550–1850BP) San Pedro de Atacama sites of Casa Parroquial, Coyo Oriental and Tchecar, enamel and bone data range from $\delta^{18}\text{O}$ (VPDB) -2.9‰ to -4.9‰, with mean enamel and bone $\delta^{18}\text{O}$ (VPDB) -4.8‰ ± 1.3 ‰ (Knudson 2009, 181). The results combined with strontium isotopes lead Knudson to conclude that only one of the individuals originated from outside the region. Knudson *et al.* (2012) used enamel and bone hydroxyapatite in order to examine paleomobility from an adult male from the San Salvador river. $\delta^{18}\text{O}_{\text{ap}}$ was -4.2‰ in early forming enamel, while archaeological human bone hydroxyapatite values were lower in both the tibia ($\delta^{18}\text{O}_{\text{ap}}$ -6.5‰) and rib ($\delta^{18}\text{O}_{\text{ap}}$ -8.1). The higher oxygen isotope value in the enamel and tibia samples are consistent with oxygen isotope data from individuals buried in the San Pedro de Atacama oases in the neighbouring highlands. The lower oxygen isotope value identified in the rib sample is consistent with values from archaeological human remains buried in the Lake Titicaca Basin (Knudson *et al.* 2012, 445).

Strontium isotopes are less problematic than oxygen and are found in rock, groundwater, soil, plants and animals. Geologic analyses of the late Cenozoic volcanics of the South Central Andes show that the patterns of geologic variability make strontium analyses possible. In the San Pedro de Atacama region, exposed bedrock samples exhibit mean $^{87}\text{Sr}/^{86}\text{Sr} = 0.70646 \pm 0.00020$ (1 σ , n= 8) and andesites from the San Pedro and San Pablo volcanoes have mean $^{87}\text{Sr}/^{86}\text{Sr} = 0.70653 \pm 0.00036$ (1 σ , n= 16) (Francis *et al.* 1977; Rogers and Hawkesworth 1989, cited in Knudson & Torres-Rouff 2009). However, since strontium isotope ratios in bedrock, soil and water within a given region can vary, the biologically available strontium isotope ratios for the regions are usually determined using modern fauna (Price *et al.* 2002). Therefore, in San Pedro de Atacama, the mean for three archaeological and modern faunal samples (cuy, dog, rodent) was $^{87}\text{Sr}/^{86}\text{Sr} = 0.70764 \pm 0.00013$ (1 σ , n= 3) with an area local range of $^{87}\text{Sr}/^{86}\text{Sr} = 0.7074\text{--}0.7079$ with 2 normal deviations. Archaeological human samples are between these ranges; therefore animal values are more representative than the geological ones (Knudson 2008).

In San Pedro, the Atacama strontium isotope analyses have been conducted in order to track mobility during the Tiwanaku period. These analyses showed that individuals associated with Tiwanaku objects were local people, although the slightly higher values in the tooth enamel of some individuals could be reflecting a differentiated access to food products (Knudson 2008). In Caspana, strontium isotopes were used during the Late Intermediate period (1100-1400BP) to determine cultural heterogeneity. Archaeological human tooth enamel gave a mean of $^{87}\text{Sr}/^{86}\text{Sr} = 0.70771 \pm 0.00038$. These isotopic data suggest that only one individual lived outside the region (Knudson & Torres-Rouff 2009).

An individual from the Salvador River (Knudson *et al.* 2012) showed higher values in early-forming enamel ($^{87}\text{Sr}/^{86}\text{Sr} = 0.70883$) than the strontium isotope values in his tibia ($^{87}\text{Sr}/^{86}\text{Sr} = 0.70745$) or rib ($^{87}\text{Sr}/^{86}\text{Sr} = 0.70806$). This variability may be the result of biogenic and diagenetic strontium in the bone samples, particularly the tibia sample. It is likely that this individual's radiogenic strontium isotope values result from the consumption of both terrestrial strontium from the coast and Atacama Desert and marine strontium from birth to death and at various scales (Knudson *et al.* 2012, 445).

Summary

The evidence reviewed above provides a clearer scenario for the potential management, consumption and use of plants in the Atacama in pre-Columbian times; however, archaeobotanical evidence is not exempt from biases due to methodological practices during the 70-90 decades when neither fine mesh nor flotation was used. Expertise in archaeobotany was not available; hence, most identifications and interpretations about the presence of macro remains were made without acknowledging the complex nature of these organic features, over or underestimating the data. In this sense, there has been a tendency to generalise the relevance of crops and technologies from a very limited number of examples that have been dated to the Formative period. Reviewing the data (Table 21), not all of the sites presented these features and their presence should be analysed within the overall context and not as immediate indicators of certain activities or economies. Micro-remains analyses are just begun to be applied in the area (McRostie 2007), and there is a lot of data that still needs to be extracted from different artefacts and contexts, as well as the need to develop good microfossil reference collections, this thesis presents a case study for this approach and a base line for future work.

Written accounts about the diversity, dispersal and use of wild plants and crops in the area are richer in some cases than in others. For instance, algarrobo and chañar are well recorded, probably because they were one of the main resources not just in diet but also as a ritual and a cultural marker of these populations, at least during proto-historical and historical times. Therefore their relevance should not be underestimated after the entrance of maize. But other wild tubers, fruits and seeds that are less well recorded should also be considered more carefully, even if today they are hardly used or valued by local populations.

Regarding crops, the information is scarce and not very precise about their varieties or their cultivation in the area. Archaeologically, *Zea mays*, *Lagenaria* and *Chenopodium* sp. have been positively identified. A starch grain of a tuber has been recorded, though only to a high taxonomical category and in an uncertain context. It has been suggested that maize was cultivated in the oases, whilst beans and cucurbits are referred to as products available for storage but not as crops harvested in the oases. Tubers and pseudo-cereals are mentioned

as brought from southern or higher areas by chronicles, just as today. Maize has been more accurately identified in archaeological research. Most of the authors agree that some kind of horticulture or agriculture complemented gathering and was practiced in the ravines and oases, especially during and after the Late Formative period. But this interpretation is justified by reference to Toconao Oriente social complexity as linked to agriculture, the development of Tumor 1, the settlement of Calar nearby river terraces, the loss of the importance of ravines during the Late Formative, or the scarce presence of maize cobs in Tumor 1, Ranl 273, Chiu Chiu 200 and Tulan sites.

Gathering activities and plant management are assumed, basically due to the presence of grinding tools since Archaic times, although not all of the sites present plant remains, and if present, *Prosopis* and *Geoffroea* are not as abundant as ethnographic and written sources would suggest. This could be due to taphonomical issues, though food choices or restrictions in where the trees grew in the past should also be considered. *Scirpus* and *Opuntia* seem to be relevant in these economies, as can be inferred from Tulan and other sites throughout the sequence.

The processing and preparation techniques in Formative times are usually assumed to be the same as in the recent past or present Andean communities. A range of plates and products are used according to different events, with chicha consumption during feasts and communal works being of particular relevance. Grinding, dehydration, salting and fermenting were the main processes used to gain better bioaccessibility and storability of the products. Today, technologies have changed to those used in modern societies, though some people still use stone and wood mortars in the preparation of foods. Chronicles and worldwide archaeology help us to understand why different morphologies of grinding tools were used. In this sense, the technological innovations, such as the shift from conical to flat mortars during the Archaic-Formative period, provide some answers, as the latter would be more efficient and less tiring, although this change could have been motivated by other concerns (e.g. new recipes, intensification of food production and processing, or more leisure time). Also, during the Archaic period, there is a recurrence of the presence of conical mortars in the ravines, which might be related to the exploitation of nearby resources. The evaluation of this latter strategy might be useful in the understanding of

cultural choices, mobility and the hunter gatherer settlement pattern. This predominance of grinding tools in the ravines is still seen during the Formative period, although their presence in the oases of the Salar de Atacama is scarce and over-emphasised due to the abundance of flat mortars in Tular 1. Similarly, the appearance of lithic hoes has been usually uncritically associated with the onset of farming or crop manipulation, when there are multiple uses that could and are given to them. These artefacts are present in residential structures and fields as well as offerings in graves.

Irrigation and storability are assumed to appear during the Early Formative and have been interpreted as a result of the rise of agro-pastoralist societies. Evidence is not abundant, with relatively few “storage” structures having been identified. But a consideration of storability should consider not just the structures but also the different techniques Andean people have used to process plants for storage. Irrigation systems become visible only with the building of solid infrastructure in later times, though flooded systems are proposed for the Early Formative, linked to a more humid period.

A brief guideline to the kilocalories per 100grms of main edible plants and animals gives us some insights into their energetic value, although it should be noted that it cannot be correlated directly with human perceptions of what plants, crops or animals were considered most valuable.

There is little bio-anthropological or isotopic data for the Formative period. Dental wear analysis, suggests a mixed diet (rich in carbohydrate plants/meat and fibre). Although the presence of wild plants that highly enriched in carbohydrates, such as *Prosopis* and *Geoffroea*, does not allow this technique to set a clear start point for the arrival of maize based on tooth wear and decay. Isotopic data indicates some access to marine products in Chorrillos and Salvador. Coprolite remains have recovered mainly wild resources from Tular 54-58.

In the next chapter, I will describe the sites sampled, which were selected because they have available one or more of the types of evidence discussed above.

CHAPTER VI. Contextualising the sites sampled

Introduction

This chapter describes the main characteristics of the sites from which samples were taken (all the photographs were taken by the author unless otherwise stated). The sites were chosen because of their chronology and location (Figure 17). Within this range, the sites selected were those that presented artefacts associated with plant processing and/or manipulation (grinding stones and lithic hoes) from which residue analyses could be done, and also those that had human remains to sample for isotopes. The sites are diagnostic for each period and had one or more types of evidence: indeed, the sampling comprised almost all of the available artefacts of this type for the area and chronology, except for the Rio Salado sites due to accessibility issues. Unfortunately materials from Loa Complex phase I-II were not available and therefore the “beginning of maize agriculture” as proposed by Pollard (1971) could not be evaluated in this sub-area. For human remains, samples were taken for almost all of the Early and Middle Formative sites, but it was only possible to take a small sample for the Late Formative (Table 26).

Some sites represent all the Formative sequence (e.g. Chorrillos, Ghatchi 2C, Tulan 67, Tulan 85) and therefore their samples will be discussed as within this broader period rather than Early, Middle and/or Late sub-periods. For contexts and images from tools, refer to Appendix 2, and for broader contextualisation of the sites, refer to CH. III: Archaeological background.

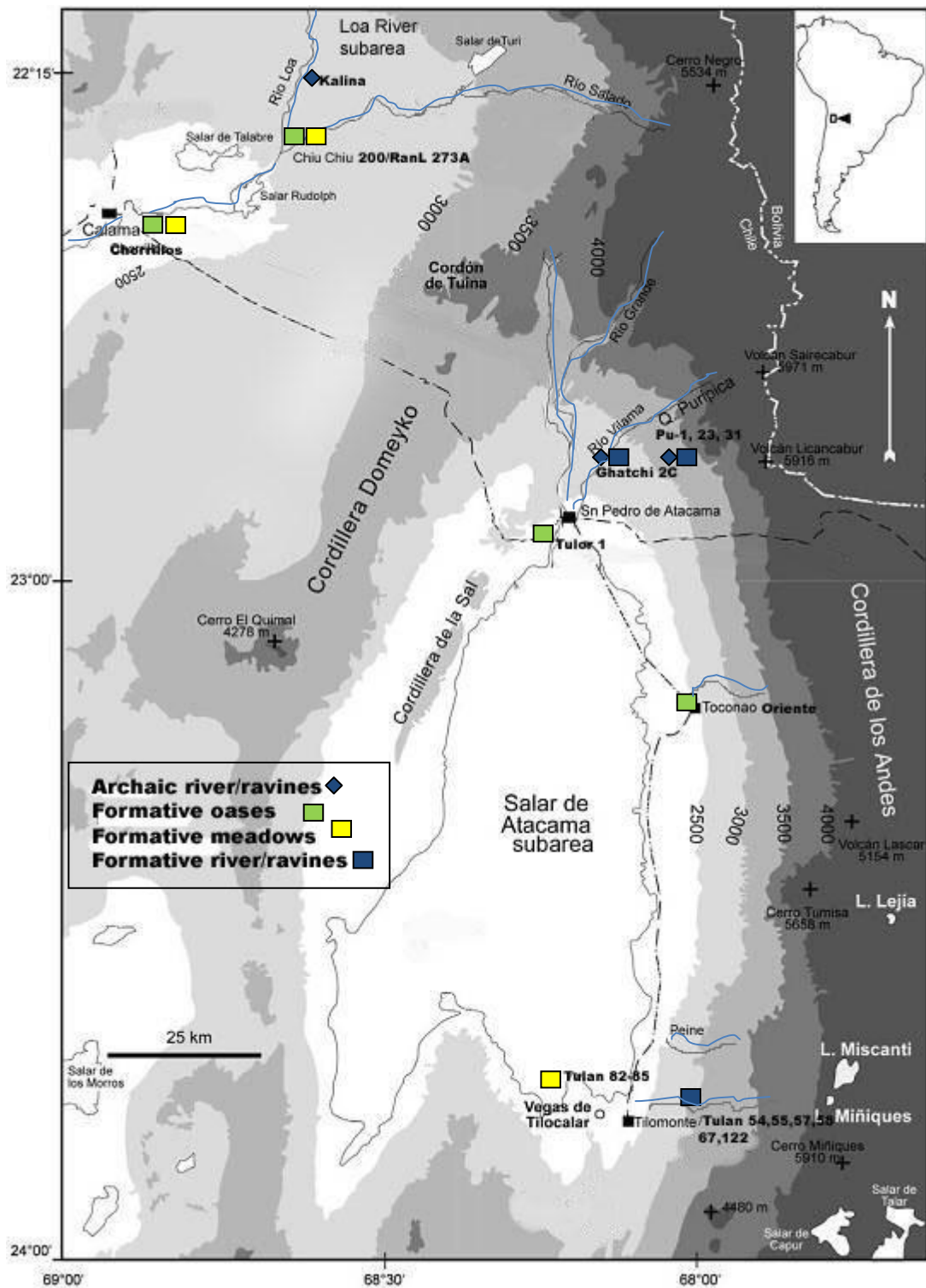


Figure 17. Chronology, location and ecosystem of the sites sampled. Adapted from Latorre et al (2003, 226)

The sites are classified following Aldunate *et al.*'s (1986) concept of settlement pattern. They defined settlements in the area as "permanent, semi-permanent and transitory according to the occupational continuity of a site. The sites that do not fit within these

categories are classified according to their specific function, such as cemetery or ritual” (Aldunate *et al.* 1986, 2), translated by V.McRostie). This nomenclature is used as a common denomination to assimilate the definitions given by different researchers to the sites under study.

Area	Period	Site	Ranges of dates BP/AD	Sampled
Loa	L.A	Kalina	4370±200 & 3950±50BP 2420-2000BC	conical mortars & manos
S.A.	L.A	Ghatchi 2C	5950-5400BP 4000-3450BC	conical mortars & manos
		Puripica 1	4290-4050BP 2340-2100BC	conical mortars & manos
Loa	E.F	Chiu Chiu 200	2910-2260BP 960-310BC	flat mortars & manos, hoes
S.A.	E.F.	Tulan 54, 55, 67, 122	Ca. 3350-2350BP Ca. 1400-400BC	flat mortars & manos, hoes- $\delta^{13}\text{C}_{\text{col/ap}}$, $\delta^{15}\text{N}$, $\delta^{18}\text{O}$ isotopes
S.A	F.	Chorrillos	2800-2140BP 850-190BC	hoes, $\delta^{13}\text{C}_{\text{col/ap}}$, $\delta^{15}\text{N}$, $\delta^{18}\text{O}$, $^{87}\text{Sr}/^{86}\text{Sr}$ isotopes
		Ghatchi 2C	Ca. 3000-1400BP Ca. 1000BC-500AD	flat conical mortars & manos
		Toconao	2300-2050BP 350BC-100AC	$\delta^{13}\text{C}_{\text{col/ap}}$, $\delta^{15}\text{N}$, $\delta^{18}\text{O}$ isotopes
		Tulan 85	3480-1520BP 1530BC-430AD	conical mortars & manos
Loa	L.F	Ranl 273	2150BP 200BC	flat mortars & manos, hoes
S.A	L.F	Tulan 57, 58, 82	2350-1450BP 400BC-500AD	flat mortars & manos , hoes
		Tulor 1	2330-2150BP 380±65BC- 200AD	flat mortars & manos, hoes
		Calar	2300-2050BP 350BC-100AD	flat mortars & manos, hoes - $\delta^{13}\text{C}_{\text{col/ap}}$, $\delta^{15}\text{N}$, $\delta^{18}\text{O}$ isotopes
		Puripica 23, 31	1760-1870BP 190-80AD	flat mortars & manos, hoes

Table 26. Sites and samples (L.A: Late archaic, E.F: Early Formative; F: Formative; L.F: Late Formative; S.A: Salar de Atacama).

VI.1 Middle Loa

The Middle Loa is the course of the river below 3000masl, characterised as a desert foothill in which scattered oases are present (Aldunate *et al.* 1986). Four sites were sampled from this area: one from the Late Archaic period (Kalina), two from the Early Formative (Chorrillos cemetery and Chiu-Chiu 200) and one from the Late Formative (Ranl 273-A).

1. Kalina, Los Morteros

Sampling: Twelve conical mortars were sampled from surface material at the site (see Appendix 2).

Chronology: Late Archaic (4370 \pm 200BP & 3950 \pm 50BP/ 2420-2000BC)

Site description: semi-permanent

Location: Middle Loa 21°58'S, 68°37'W (3100masl), ravines (Aldunate *et al.* 1986). Located in the plateau of a dry stream which drains into the Loa River, the site itself is on a rocky and steep terrain with scarce and scattered flora (e.g. *Atriplex imbricata*, *Acantholippia deserticola*); whilst the Loa riverside presents a dense cover of aquatic plants such as Cyperaceae, *Cortadera* sp. as well as other grasses (Figure 18).

Excavated during the 1970s and 1980s, the site is a semi-permanent camp with around twenty-four semi-sunken rock structures (3000m²). The surface is covered with lithic materials, with a notable number of exhausted conical mortars (Figure 19). Four stratigraphic layers were identified, with a mean depth of 35cm. C¹⁴ radiocarbon dates gave two occupations of 3950 \pm 50BP and 4370 \pm 220BP, which relate to the same settlement with discontinuous occupation (Aldunate *et al.* 1986, 91). This site also presents the earliest expression of the Kalina style of rock art. Some materials recovered from the excavations are small and large mammal bones, fragments of marine shells, drills and points. Aldunate *et al.* (1986) suggest that this was a plant processing station, though no archaeobotanical analyses have been carried out on the site nor macro-remains reported during excavations. In terms of cultural relations, this site is described as hunter-gatherers related to Chiu-Chiu and Puripica Complex from the Middle Loa and Salar de Atacama respectively.



Figure 18. Loa riverside.

Figure 19. Kalina site.

2. Chiu Chiu 200

Sampling: Eighteen mortars, *manos* and hoes were sampled from museum premises (see Appendix 2).

Chronology: Early Formative (2910-2260BP/ 960BC-310BC)

Site description: semi-permanent

Location: Middle Loa, in the confluence with the Salado River (2500masl). The site is located on the higher terrace to the east of the Loa River, in a limestone terrain at 700m to the north of the actual town of Chiu-Chiu and nearby Chiu Chiu meadows and oases. In the meadows, *ch'ampas* includes different species of *Scirpus* (*deserticola*, *atacamensis*) and grasses such as *Distichlis spicata*, *Eleocharis* and *Triglochin striatum*, among others. In the oases, shrubs are mainly *Atriplex sp.*, *Acantholipia deserticola* and *Thessaria absinthioides*; *Prosopis* and *Geoffroea* trees are also abundant.

This site has been defined as a semi-agglutinated village that is thought to have been used seasonally – during winter - by pastoralist groups that managed llama herds. With an area of 28.693m², the village is formed by a series of semi-circular habitation structures which show a regular pattern in their construction, only one stratigraphic component or singular phase has been identified with a mean depth of 1.20m (Benavente 1982; 1988-1989). Remains of fires in the floor as well as grinding tools allow us to interpret it as a habitation site. Small nuclear family units would occupy the structures to sleep, eat and have some refuge during

their quotidian activities such as herding, hunting and gathering. Each family would have their own stock of animals, which they would pasture in the nearby meadow of Chiu Chiu. Benavente (1982) suggests that the main role of the llama was as a transport animal. Among the findings, Benavente (1982) describes different fleeces and textiles from wild as well as domestic camelids. Macro-remains of wild resources such as plant fibres, seeds and wood from different species (*Geoffroea decorticans*, *Tessaria absinthoides*, *Prosopis* sp.) and coiled basketry have been found, as well as a few macro-remains of small *Zea mays* cobs and panicles, *Lagenaria* sp. and *Gossypium* sp. fibre. Lithic hoes and conical and flat grinding stones are part of this assemblage (Benavente 1982; 1988-1989), and hoes are very small in relation to later periods (Cartajena 1994). The high percentage of grinding stones (conical and flat mortars) is not comparable with other hunting-gathering sites, suggesting a greater dependence on plants (Jackson & Benavente 1995). Other common features are ropes, lithic debris, cores, pre-forms and artefacts such as knives, scrapers, drills, beads, marine resources in small quantities, mammal bones, leather and feathers. Also there is a change from the previous microlith tradition to larger parrot-beak piercing tools and stemmed projectile points with a concave base. This material does not reflect a hunting economy but clearly an agro-pastoralist one (Jackson & Benavente 1995). For Benavente (1982; 1988-1989), this tradition represents a discontinuity with the previous Late Archaic Chiu Chiu complex. This early village has been linked with Northwestern Argentina and Bolivian highland developments, which have been interacting with local populations not just in the Loa basin but also in the Salar de Atacama (Chorrillos, Tilocalar). These relations would imply a multidirectional flux, the nature of which is still not well understood, though for the author it suggests an interchange of services and wealth trades using the llama in this incipient but growing caravan system.

3. Ranl 273A

Sampling: Six grinding tools and two hoes were sampled from museum premises (see Appendix 2).

Chronology: Late Formative - Vega Alta II (ca 200 BC/ 2150BP).

Site description: Semi-permanent

Location: Middle Loa near Chiu Chiu 200 site (2500masl).

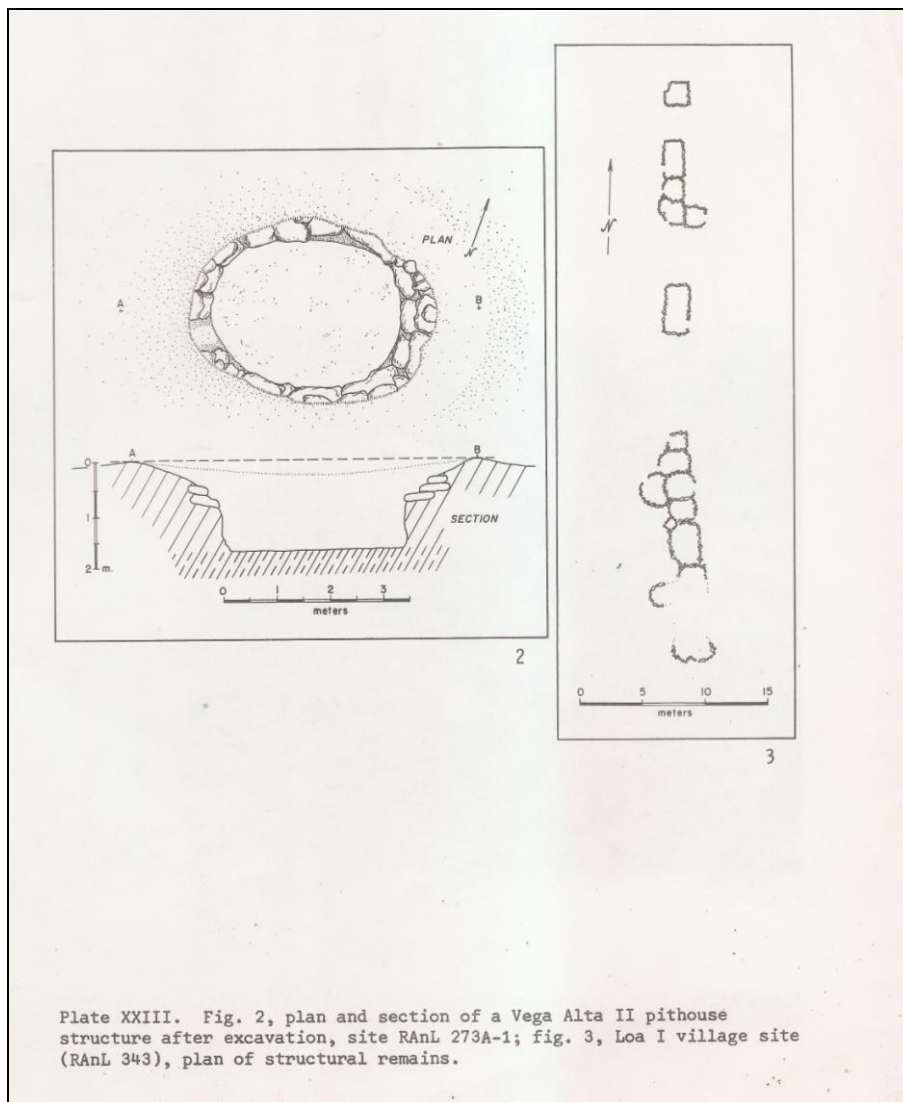


Figure 20. RAnL 273-A. Reproduced from (Pollard 1971, 45).

This site is part of the terminal stage of the Vega Alta II phase. This semi-permanent village is located to the north-west of the Loa River on barren ground above the river, with smaller temporary encampments located near exploitable resources from oases and meadows, being part of at least ten circular pit-houses recognised as shallow surface depressions of 4.5-6.5m in diameter and 1.7m deep (Figure 20). Cultural materials are plants such as *Cortadera* and junquillo, small quantities of *Prosopis* seeds, rhizomes, cactus, gourd, one *mano*, mortars, projectile points, bone and stone beads, sea shells, pottery, coiled baskets, camelid bones and disarticulated human bones. These occupants of this site appear to have been continuing a hunter-gatherer way of life similar to that of the Late Archaic Chiu Chiu

Complex with the potential addition of some llama herding. The llama was probably introduced around 500BC (Pollard & Drew 1975). Even though direct evidence of llama is lacking, “such an economic shift would have made possible the larger and more permanent settlements of this period” (Pollard 1971, 46).

Benavente (1982) considers that Vega Alta I and Vega Alta II (1400-500BC and 500-200BC) are part of the same period and that the separation of these two phases relies on the functionality of the sites. For Benavente (1982), Ranl 273 was part of the central base camp of Chiu Chiu 200 and therefore llama was present at the initial stages of the Formative period. Also Benavente (1982; 1988-1989) considers that there is a discontinuity among Late Archaic Chiu Chiu Complex and Formative groups due to the strong influences from foreign populations in the area.

4. Chorrillos

Sampling: Thirteen hoes were sampled for residue analyses, as well as four individuals for $\delta^{13}\text{C}_{\text{col/ap}}$, $\delta^{15}\text{N}$ isotopes and five individuals for $^{87}\text{Sr}/^{86}\text{Sr}$, plus two rodents were sampled from museum premises (see Appendix 2).

Chronology: Formative (2800-2140BP/850-190BC).

Site description: Cemetery.

Location: Middle Loa, Calama oases/meadows, at 2260masl and 250m from Loa riverside. The Loa River in this area is very salty, as it has already mixed with the Salado River. Native vegetation nowadays is mainly composed of species that colonise disturbed habitats, such as *Distichlis spicata*, *Thessaria absinthoidies* and *Baccharis petiolata*. Other common species are *Baccharis juncea*, *Lycopersicon chilense*, *Cortaderia atacamensis* and species of Juncaceae (*Juncus arcticus*, *acutus*) and Cyperaceae (*Scirpus americanus*, *riparia*), as well as *Prosopis* and *Geoffroea decorticans* trees. Indigenous crops such as maize are still planted along side more recently introduced crops such as alfalfa and various vegetables.

The site is composed of 283 tombs, of which twenty-four were empty whilst others had multiple burials. In total, 353 individuals were recovered from 259 tombs. The residential sites that this population originated from have not yet been found. The tombs are

exclusively from the Formative period, being very homogenous through time. In general, they have similar funerary patterns, with circular oblique cranial deformation, as opposed to the Salar area, where it is mainly tabular erect (Munizaga 1987, cited in González & Westfall 2006). Also, the health conditions are similar for all individuals. The presence of adults and infants suggest the presence of discrete familiar units. Among cultural elements recovered are five types of Formative pottery (n= 820 fragments), beads and minerals, lithic hoes (=14, eleven with men, two with one women and one with an unidentified individual), with individuals whose age ranged between twenty and forty years. This tool has been hypothesised as a horticulture indicator. Due to the humidity of the soil, organic preservation was not very good; some plants such as Cucurbitaceae and *Chenopodium* sp. were recovered (Belmar & Quiroz 2005), the latter suggesting connections with the highlands. Lithic points suggest hunting activities (n=8). These points present irregular morphologies, though they become smaller, as has been tracked in other Formative sites, being representative of Early Formative transition in the area. Also textiles from camelids, five big camelid bones (guanaco/llama) and one leg, probably from a llama as an offering, were recorded, among other bone artefacts that included an exotic parrot. Ninety-four individuals present shells artefacts, as well as a replacement of an infant skull by an *Argopecten purpuratus* shell. Two *Strophocheilus oblongus* from tras-Andean latitudes were encountered. Finally three gold laminar pendants were found associated with infants, just as at the Tulan 54 site.

For (González & Westfall 2006), this is a distinctive group which presents a local phase, “Chorrillos”, which also includes other nearby cemeteries such as Topater and Villa Chuquicamata, although each has its own particularities, such as tembetas in Villa Chuquicamata and a later occupation in Topater (200BC onwards). This population would have complemented its economy through exchange with inner and coastal populations by an increasing caravanning system. Cultural materials allow us to see common features between this site and communities such as Chiu Chiu 200, 273, 275 and the Vega Alta complex in the Middle Loa; Tilocalar in the Salar de Atacama and Early Middle Formative groups from San Pedro oases. For the authors, the inner population would have relied more on a pastoralist economy whilst the former are thought to have had a major horticulturalist

inclination due to differential tooth wear and because some of them (3.6%) have been buried with lithic hoes. Also preliminary analyses of stable isotopes ($\delta^{15}\text{N}$) showed an individual with a $\delta^{15}\text{N}$ value of 14.7‰, which, being higher than 12, allows the proposal of a moderate ingestion of marine resources, and another case with a $\delta^{15}\text{N}$ value of 10.7 ‰ without marine consumption. Preliminary DNA analyses in Chorrillos groups related them with the haplogroup B (Moraga *et al.* 2006), which would be part of the third migrational wave coming from the Bolivian Highlands around 1000BC. This cemetery highlights the relevance of Calama oases during the Formative period, prior to the hegemony of San Pedro and the Atacama oases during later times.

VI.2 Salar de Atacama area

The main sites in this area are located either in the northern or the southern part of the Salar. They are located in ravines and rivers which drain into the Salar de Atacama and in the oases and meadows surrounding it (see Figure 17). Most of the sites sampled are located in the ravines and rivers. Two Late Archaic sites were sampled from the Puripica/Vilama rivers: Puripica 1 and Ghatchi 2C, and in this same area, four sites for the Early and Late Formative: Puripica 23, 31, Calar and Ghatchi 2C. Moving towards the south, Tulo 1 is located in the San Pedro de Atacama oases, then 38 kms to the south, Toconao Oriente is located in the Jerez ravine and 70 kms to the south, eight sites from the Formative period were sampled in Quebrada Tulan (Tulan 54-55-57-58-67-82-85-122).

Northern area

Puripica 1, 23, 31

Chronology: Late Archaic and Late Formative

Sites description: semi-permanent, permanent

Location: 30 kms northwest of San Pedro de Atacama ($\pm 3500\text{masl}$). Quebrada Puripica is a tributary of the Puritama River, which joins with the Vilama River at Guatin, where irrigated fields are cultivated (Dransart 2002; Stehberg 1974). Vegetation is characterised by the frequent occurrence of *Trichocereus atacamensis*, which provide edible fruits as well as

wood for construction. Here grasslands are abundant, as well as aquatic plants in nearby waters, such as *Scirpus* sp., *Baccharis juncaea*, *Cortadera atacamensis*, *Juncus* sp. Other flora present in the area includes *Opuntia* sp., *Atriplex* sp., *Acantholippia deserticola*, *Thessaria absinthioides*, among others. Núñez *et al.* (1995-96) suggests that Late Archaic sites such as Puripica 1 were allocated in paleo- wetlands produced by a blockage of the waters, which afterwards, during Formative times, would have unblocked, giving rise to the actual fluvial course of the Puripica ravine where Formative sites such as Puripica 31 and 23 were settled.

5. Puripica 1

Sampling: Only one *mano* was available for sampling in the museums (see Appendix 2).

Chronology: Late Archaic (4050 ± 95 BP and 4815 ± 70 BP/ 6000-6700BC).

Site description: semi-permanent

This site is located in the high border of Puripica gorge and represents the final phase of occupation in the ravine during the Late Archaic period (Núñez *et al.* 1999). Locally the site is known as *Los Morteros* due to the high abundance of exhausted and broken conical mortars on the surface of the 400m² site (Figure 21) (Núñez 1981b; Núñez *et al.* 1995; Núñez & Santoro 1988). Excavations of 27m² with a stratigraphy of 70-80cms deep were performed at the site, revealing four stratigraphic layers in circular pit houses similar to those found at the Tulan 52 site (Núñez 1981a) (Figure 22).

Because knives and scrapers are more abundant than projectile points, Núñez (1981a) considers that people were skinning animals and working hide. Camelids' bones predominate in the samples. Hesse (1982b), based on several indicators, proposes that camelids were developed at this site by around 4000BP. The proposition that domestication occurred at Puripica 1 is supported by the diminution of projectile points, the presence of blocks incised with depictions of camelids and the presence of *Lama glama*. Mortars and *manos* suggest processing of plants, though no archaeobotanical analyses were done and no macro-remains have been reported so far. In this case, the humidity of the site might have biased against the preservation of botanical remains. Therefore, this site represents

increasing complexity related to a more sedentary pattern, an intensification of grinding activities, domestication of camelids and the presence of rock art, among other features. This population is related to contemporaneous complex hunter gatherers of the Middle Loa (Chiu-Chiu complex, Kalina) and with Tulan communities (Tulan 52).

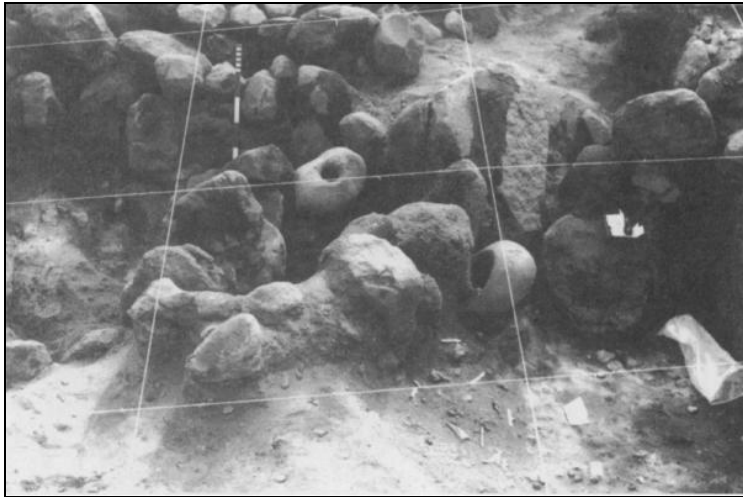


Figure 21. Conical mortars in Puripica 1. Reproduced from (Núñez *et al.* 1999, 168).

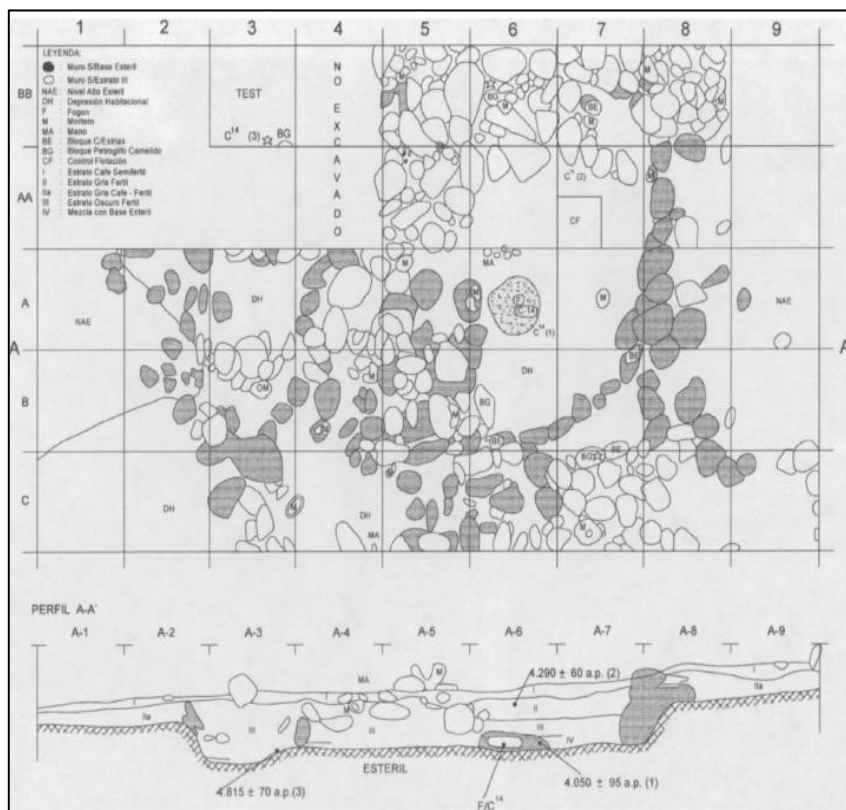


Figure 22. Puripica 1 plant and profile. Reproduced from (Núñez *et al.* 1999, 167).

6. Puripica 23

Sampling: Two *manos* and five hoes from museum premises (see Appendix 2).

Chronology: Late Formative (1760 \pm 80BP/ 190AD).

7. Puripica 31-A

Sampling: Five *manos* and four hoes were sampled from museum premises (see Appendix 2).

Chronology: Late Formative (1640 \pm 70BP/ 310AD).

Sites description: semi-permanent

The occupation of these sites started when the ravine was cut by the flow of previously blocked waters. Under a fluvial morphology, a more intense and dispersed pattern of settlement happened. Although these groups continued to use hunter-gathering activities for their sustenance, by the Late Formative they were also engaged in some agriculture and llama herding and for the first time mining-metallurgy activities (Núñez *et al.* 1999). Puripica 31 is divided into sectors A and B, covering around 900m². The former is made up of dispersed campsites of 16m², one of which was excavated (Puripica 31). Four stratigraphic layers each have distinct material culture. A date of 310 \pm 70AD was taken from layer II, which is the initial occupation of the site and representative of the Late Formative. This layer represents the climax of occupation. Associated with the charcoal dated were camelids' bones and dung, lithic hoes, pottery, eleven remains of maize and algarrobo seeds. Here local hunting and herding predominates among agricultural labours which could have been performed in the riverbed on a small scale. Gathering and altitudinal movements are represented by algarrobo seeds, which were probably collected in San Pedro oases.

Puripica 23 is located on the summit of the ravine. It has two conglomerated and two isolated structures, composed of fifteen houses and storage circles around 6-8m within ca. 936 m² (Figure 23). This architecture is similar to Tulor 1. The surface of the site presents Formative pottery and lithic hoes. The excavations also present hoes, projectile points, llamas and dung. Initial occupation was dated to 190 \pm 80AD. Núñez *et al.* (1995-96, 281)

describes this as the time that flat mortars appeared. Agriculture activities are thought to have been performed in the lacustrine soils, where irrigation canals and terraces would have supported discrete plantations (Núñez *et al.* 1995-96), although, due to the altitude and climate conditions, these agricultural activities would have been possible only in certain seasons and for just some sorts of cultivars (Stehberg 1974).

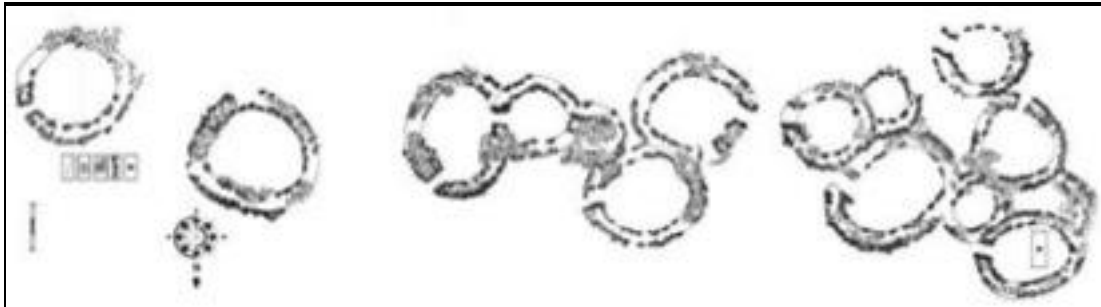


Figure 23. Plan of village Puripica 23. Reproduced from Núñez (2005, 176).

8. Ghatchi 2C

Sampling: Twenty-two grinding tools were sampled from the surface of the site (see Appendix 2).

Chronology: Late Archaic and Formative

Site description: Semi-permanent

Location: The site is located on the northern plateau of the Vilama River 15 kms North-East of San Pedro de Atacama at 2700masl. The surface of the site is almost lacking in vegetation (Figure 24), though the riverside of Vilama has aquatic plants and grasslands such as *Cortadera atacamensis*, *Thessaria absinthioides*, *Scirpus* sp. and *Distichlis spicata*.



Figure 24. Vilama River from Ghatchi site.

This site has eighty-one circular, semicircular and oval structures, hardly agglutinated (Figure 25). It has at least three occupational moments, the first one from the Late Archaic period (4885 ± 125 BP, 4000-3350cal.BC), the second from the Early Formative and the last one the Middle-Late Formative (Agüero *et al.* 2009).

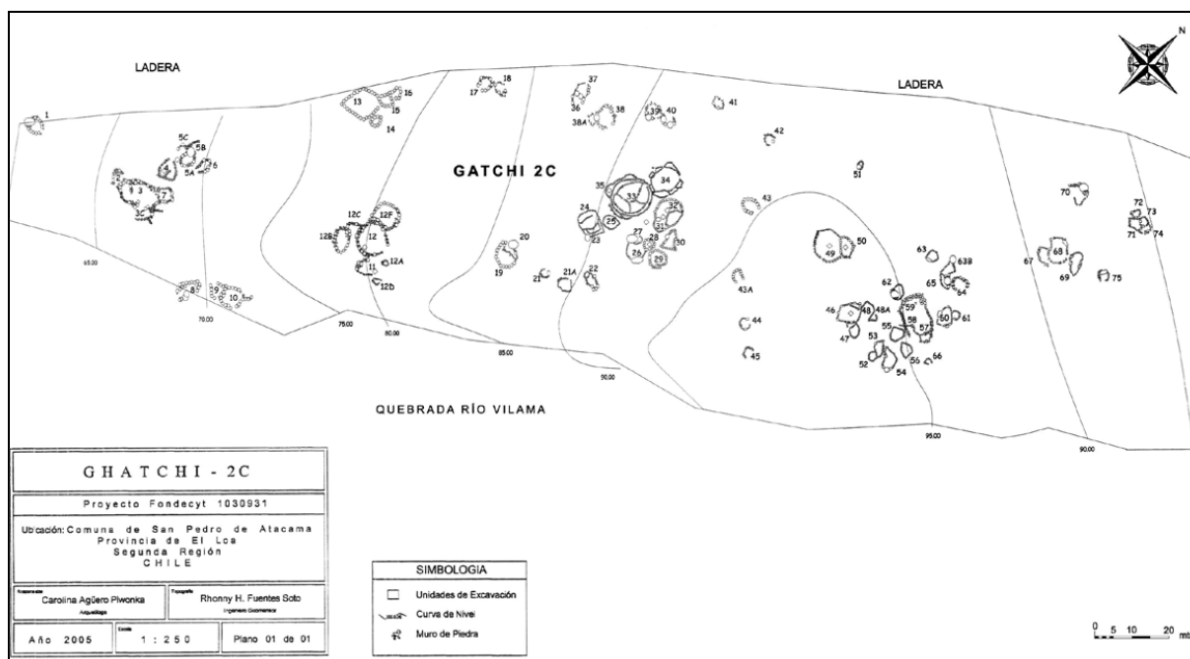


Figure 25. Ghatchi site. Reproduced from Adán & Urbina (2007, 20).

Based on the architectural patterns, Adán & Urbina (2007) suggest an occupation during the Late Archaic and the Formative periods. The former would have been related to seasonal hunting activities, whilst the latter might be related to herders, as the structures are made up of a major circle surrounded by smaller ones, which could be used as corrals, though the authors also consider the possibility that these structures are part of public sites related to the rise of complexity during the Early Formative and which would be related with contemporaneous developments in the area (e.g. Tulan 54). The presence of cultural materials in the site is extremely low (pottery, lithic debris and artefacts, camelids and small bones, plants), though there are 211 exhausted conical mortars on the surface and more reused in the walls of the bigger structures (Figures 26 and 27). These artefacts are a diagnostic element for the Late Archaic period, relating it to the Kalina and Chiu Chiu complex in the Middle Loa, and to Tulan and Puripica-1 within the Salar.

Corresponding to the Early Formative, one lithic shovel, cf. *Chenopodium* sp. and surrounding wild plants macro-remains have been found in low frequencies (Vidal 2007). Also five conical and extended mortars, four *tacitas*, four *metates* and three *conas*, as well as twenty *manos* were found in the surface of the site (Agüero & Uribe 2011), which probably represent the Formative occupations. Therefore this site might have been a semi-permanent campsite more related to discrete and short episodes of hunting-gathering and

later with herding. The main activity was probably the procurement of lithic raw material. Due to its strategic position between the oases of San Pedro and the highlands and the Loa River, this site could also have served in the articulation of different areas with complementarity resources (Agüero 2005; Pimentel 2008).

The sampling of this site was made based on manuscripts from the excavations and surface survey. In this sense, Formative mortars are assumed due to their location in structures described as Formative as well as the flattened morphology. All the conical mortars were assumed to be archaic technology.



Figure 26. Formative structures Ghatchi 2C. Figure 27. Exhausted mortar in structure.

9. Calar

Sampling: Five hoes and three grinding tools were sampled. Four skulls from individuals were sampled for $\delta^{13}\text{C}_{\text{col}}$, $\delta^{13}\text{C}_{\text{ap}}$ and $\delta^{15}\text{N}$ isotopes. The samples were taken from museum premises (see Appendix 2).

Chronology: Late Formative. ca. (2150-1604BP/ 200BC-346AD)

Site description: Semi-permanent, cemetery, agricultural terraces.

Location: This site is in the first terrace of the Vilama River, downstream from the Ghatchi location at 2650masl. Here the valley gets wider and therefore becomes more suitable for agricultural and herding activities. Actual vegetation is primarily composed of aquatic species such as *Scirpus* sp., *Juncus* sp., *Cortaderia atacamensis* and grasses like *Distichlis spicata*.

The village is composed of thirty-four semicircular stone structures surrounding two large squares where Le Paige (1963) excavated twenty-five tombs (Figure 28). Adán & Urbina (2007) also describe conical mortars on its walls. At the height of occupation this site must have sustained around 150 people (Orellana 1988-1989). In the excavation, Le Paige mentions that they found lithic flakes related to the creation of instruments associated with early agriculture in the region (hoes). Afterwards Orellana (1988-1989) and Llagostera (1988) found agricultural tools (hoes) as well as *Prosopis* seeds, cactus thorns, and grinding tools. All this evidence was related to a terrace near the river, leading to the hypothesis that it was an agricultural field. Orellana (1988-1989) proposes that these populations would have had mixed economies combining agro-pastoralism with hunting and gathering. He also points out that the circular and semicircular constructions are similar to Eastern Puna and Meridian Andes, and that this foreign influence may have promoted the consolidation of agropastoralism villages such as Tulo 1 in the oases of San Pedro; and that in this village, social stratification would have been present. For Adán & Urbina (2007), the construction pattern has its referent on the Circumpuna, especially on high gorges, the Bolivian Highland and Northwestern Argentina, though there are also similarities with the ancestral pattern present at the mouth of the Loa River, by the coast. For these authors, Calar would be located on exchange routes and in a place where they could access different areas and ecologies. Later excavations established that there was an important lithic industry where microlithic and agricultural artefacts such as *manos*, flat and conical mortars were present, as well as pottery, which also links this site to Early Formative populations (Vidal 2007). Archaeobotanical remains are scarce: *Prosopis* sp., *Geoffroea decorticans* and Cucurbitaceae corresponding to Early Formative and Middle period (Vidal 2007, 118). Due to the scarce material, this village, like the Ghatchi sites, is better understood as a stationary settlement related to discrete activities of hunter/pastoralism but mainly for the supply of lithic raw material and redistribution of items (Vidal 2007, 126-127). The semi-permanent pattern coincides with the general patterns of the sites of the period in the ravines as well as in the oases (Agüero 2005; Agüero & Uribe 2011).

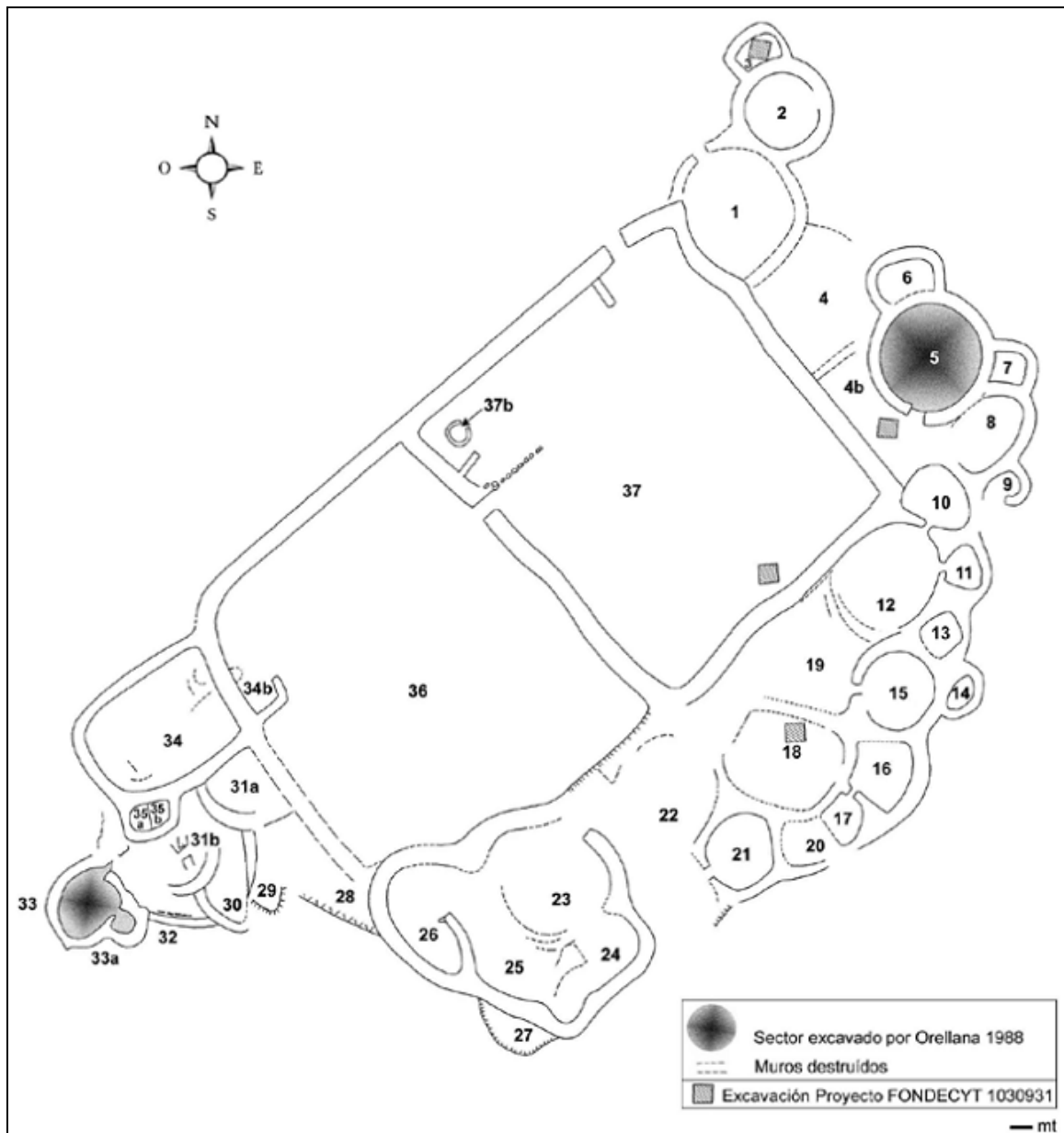


Figure 28. Calar village. Reproduced from (Adán & Urbina 2007, 18).

10. Tulor 1

Smplng: Thirteen *manos* and nine lithic hoes were sampled from museum premises (see Appendix 2).

Chronology: Late Formative (400BC-100AD/ 2350-1850BP).

Site description: permanent occupation

Location: Southwest of the San Pedro oases where Rio San Pedro used to end and the waters were filtered underground, providing enough humidity for the formation of lagoons, meadows and moist soils suitable for agricultural and grazing activities (2300masl). Beside the aquatic flora and salty grasses, common oases vegetation such as *Prosopis*, *Geoffroea*, *Atriplex*, *Acantholippia* and *Baccharis* might have been abundant.

Le Paige was the first to mention this site, saying that it is a very old village covered with sand where there are submerged grinding stones and other work tools (Le Paige 1958, 66). With excavations, it was discovered that this was a complex village system of 5600m² made up of around ten non-structured and structured sites, one of the largest being Tulor 1 (3000m²) (Figure 29). Tulor 1 has around twenty-two mud structures with circular and irregular plans surrounded by mud walls of around 2m in height (Llagostera *et al.* 1984). These structures have been categorised with different functions such as habitations, storage areas, public spaces and corrals (Adán & Urbina 2007; Barón 1986; Llagostera *et al.* 1984). The increasing segmentation of Tulor 1 through the outgrowth of the village has been interpreted as a hierarchization of the system (Llagostera *et al.* 1984). Stratigraphy reveals the same event in all the excavated areas, though two horizons are segregated. The first one is on the actual surface and the other is on the floor of the structures. Both are separated by a sterile sand layer of around 1.20cms (Llagostera *et al.* 1984). Barón (1986) characterises these occupations as Tulor I phase (400BC-100AD predominating 200BC and 100AD dates) with a residential function; and Tulor II (100AD-400AD) when it was reused as a cemetery. Therefore the surface materials are remains of debris wiped out of the mud walls during the period of site reuse for a cemetery. The village occupation is composed of a layer of $\pm 10\text{--}30\text{cm}$, which has two main components: a clay stratum and below it a sandy one, in which can be distinguished eolic thin sand grooves. The floor occupation was dated around $150\pm 60/100\pm 60\text{AD}$ (Llagostera *et al.* 1984).

Among the cultural materials found in the Tulor I village, almost 100% of the bones are camelid, but cannot be identified at a specific taxonomical level. The bigger specimens were found in structure 7, which is characterised as a corral and has dung layers. The parts of bones found within the habitation structures suggest that animals were slaughtered outside them. Also scarce rodent bones and marine shells related to ornamentation and religious

practices were found. Plant macroremains are poorly conserved, with just some charred remains, especially in pits which have a “good quantity of *Prosopis chilensis* and *Zea mays*” (Llagostera *et al.* 1984, 138), establishing their storage function. Pottery is present with different manifestations among the two occupations. Other miscellaneous materials are exclusively present, related to the village occupation. These are projectile points, drills, axes and hoes, lithic debris and cores, polishing stones, flaked tools, knives, scrapers, flat stones, mortars (conanas), usually broken, and *manos*. Also, bone artefacts, beads, yellow and red pigments are in the assemblage (Barón 1986; Llagostera *et al.* 1984). Carrasco (2006) points out that conical mortars are also present at this site.

This evidence led previous authors (Agüero 2005; Barón 1986; Llagostera *et al.* 1984; Llagostera & Costa 1999; Núñez 2005) to place an emphasis on maize production within the development and support of this village, relegating the role of herding primarily to the ravines, though some of them do not deny the grazing of herds in damp areas surrounding Tulor and their management in the corrals as well as the gathering of tree resources. Agriculture evidence on the site comprises large lithic hoes, charred maize, *manos*, conanas and morteros. Also, its establishment at the terminal of the San Pedro River has been used as diagnostic of irrigation by floods, although, the horticultural fields must have been swept away or buried by San Pedro River floods, in some cases carrying 1-2m mud into the site. Also this site is entirely exposed to sand deposition, making it harder to visualise any agriculture field, if present (Barón 1986; Llagostera *et al.* 1984; Llagostera & Costa 1999; Núñez 2005; Tarragó 1989).

Recent analyses questions the emphasis in agriculture because of the scarce macroremains of Cucurbitaceae and *Zea mays* present in the assemblage (Vidal 2007), and therefore more relevance has been given to forest resources (Agüero 2005; Agüero *et al.* 2009; Vidal 2007). Vidal (2007) contends that even if the evidence is scarce, there “should be an important quantity of cultivated maize to support complex sites as Tulor 1 and Toconao Oriente” (Vidal 2007, 116) and that the question of preservation should still be reevaluated.

Tulor 1 has been mainly described as the culmination and hallmark of sedentism in the area, though Dransart (2002), based on the stratigraphy of house 2 at Tulor 1, questions the continuity of the occupation due to a thick accumulation of sand between the two

occupation layers, proposing that the house was abandoned for an as yet undefined period of time, and that seasonal or periodic occupation occurred, even though at first sight this site may seem characteristic of a permanent settlement (Dransart 2002, 198).

Finally, this village inaugurates a tradition of construction based on the knowledge of mud and adobe that would last on the oases throughout all the pottery periods (Adán & Urbina 2007). It has been suggested that this constructive pattern is original from the Bolivian Altiplano founded on the Wankarani site (1200BC) as well as being related with North-Western cultures such as the Aguada, Tafi and Cienaga (Llagostera *et al.* 1984, 140-41). The rise of this village also has similarities with northern contemporaneous developments such as Caserones and especially Guatacondo village on Tarapaca. This development represents what was going on in the Andean Puna during the Formative period. Tulo was integrated with a bigger universe, which goes from the coast to the highlands and lower lands of the east, being a focus of cultural and social interaction during that time (Llagostera *et al.* 1984, 142).

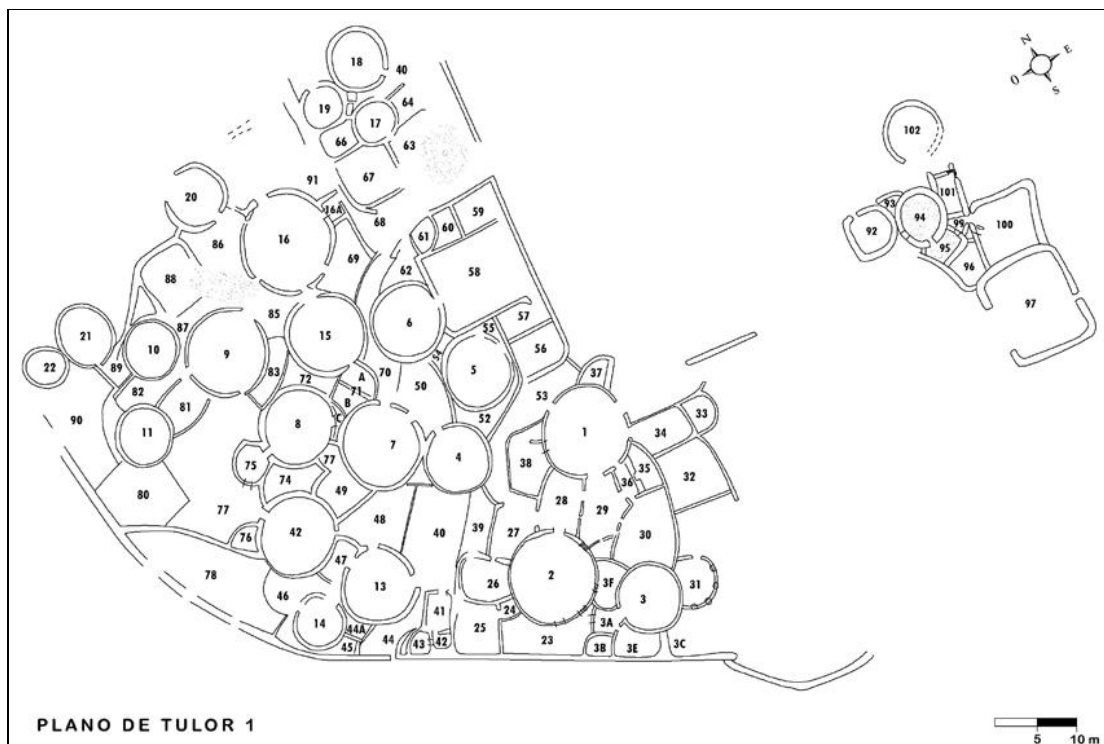


Figure 29. Tulo 1. Reproduced from (Adán & Urbina 2007, 14).

Southern area

11. Toconao Oriente

Sampling: Five individuals were sampled for $\delta^{13}\text{C}_{\text{col}}$, $\delta^{13}\text{C}_{\text{ap}}$, $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ isotopes (see Appendix 2).

Chronology: Late Formative (350BC - 690AD/ 2300-1260BP).

Site description: cemetery

Location: 38 kms south of San Pedro de Atacama at 2500 masl. This site is situated on the plateau of Quebrada Jere where the Toconao River gives rise to a fertile area in which the village of Toconao is located. Nowadays this area is intensively exploited for agricultural and tourism purposes. Vegetation has been altered almost entirely due to the planting of exotic trees and maize. However, aquatic plants such as *Scirpus*, *Cortadera*, *Juncus*, *Distichlis*, among other wetland grasses, still grow nearby the stream and *Prosopis*, *Geoffroea* as well as desert shrubs are also present in the surroundings plateaus.

The cemetery is composed of 368 tombs, though the residential sites have not yet been found (Figure 30). The complexity of their contents shows the degree of centralisation that San Pedro populations gained around the Late Formative period and also suggests the capacity to generate surplus. This wealth has been related to an agro-pastoralist system linked to Tulo 1 development (Bittmann *et al.* 1978; Llagostera 1996; Tarragó 1984). The offerings show a strong connection with foreign areas such as the Meridional Altiplano and Northwestern Argentina (San Francisco), leading to the proposal that this is the period of foremost “orientalisation” (Tarragó 1984, 97). The sophisticated and diverse offerings found differently among tombs have led to the proposal of emerging elites, which would have relied on agricultural surplus (Llagostera 1996; Tarragó 1989). Among the vegetal offerings, only Cucurbitaceae rinds and *Prosopis* sp. pods have been found. Unfortunately there are no bio-anthropological reports for this site.



Figure 30. Toconao Oriente site. Reproduced from Le Paige (1973, 170).

Tulan ravine sites.

Descriptions based mainly on (Núñez 1986-1987; 1995; 2005; Núñez *et al.* 2006; Núñez *et al.* 2009).

Excavation: Fondecyt 101786, 1020316

Location: 200kms south east of San Pedro oases, Quebrada Tulan is one of the most southerly of a number of ravines draining into the Salar. This ravine emerges from a spring at 3100masl which flows into the oases of Tilomonte (2300masl). The riverbed is narrow and cut deep in the limestone plateaus, though it varies in width through its course. Abundant grasses and aquatic plants grow near the stream (*Scirpus* sp., *Juncus* sp., *Cortadera* sp., *Distichlis spicata*, *Baccharis juncea*) as opposed to the adjacent environments where scattered shrubs and herbaceous plants are present (*Opuntia* sp, *Cisthante* sp., *Atriplex*, *Ephedra*, *Acantholipia*, *Thessaria absinthioides* etc). In the oases itself there are populations of *Prosopis* and *Geoffroea* and nowadays maize and alfalfa (*Medicago sativa*) are cultivated. From the highlands to the salar, there are different altitudinal belts (puna, ravines and oases). All of them were used seasonally by native populations according to the availability

of flora and fauna resources. Also nearby ravines, now dry, might have been activated during summer rains and therefore been more suitable for the establishment of settlements in the past.

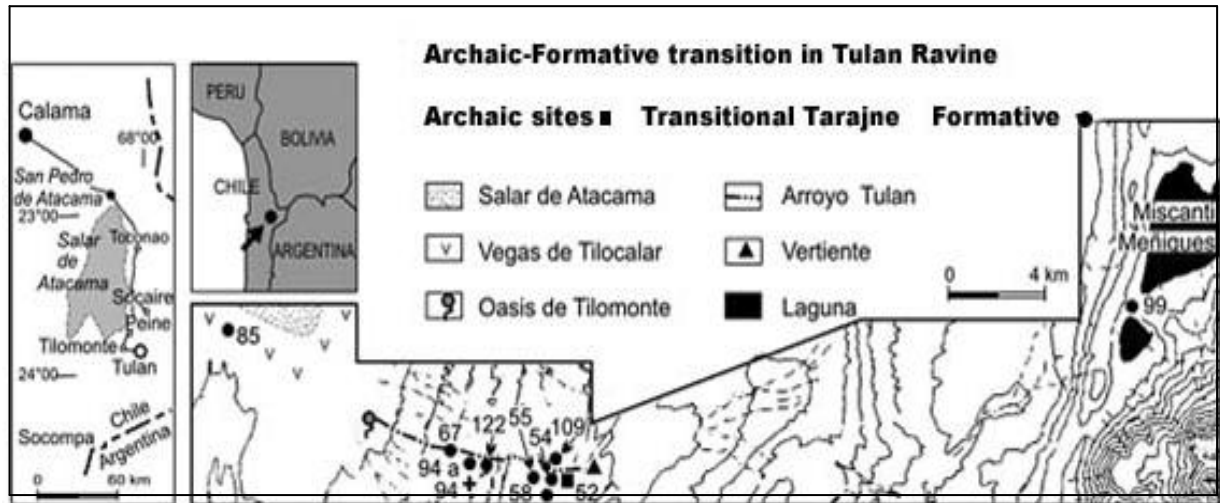


Figure 31. Tulan ravine and major sites. Reproduced from (Núñez *et al.* 2006, 94).

More than 108 sites have been registered in the Tulan (Figure 31). For the purpose of this study, only eight sites were sampled (Tulan 54-55-57-58-67-82-85-122), mostly within the Tilocalar phase (3500-2400BP/ 1550BC-450BC). These sites represent different settlement patterns. Open sites includes habitational (Tulan 57, 82, 85, 122) as well domestic-ritual sites (54), which are more permanent occupations. Caves (Tulan 55, 67) are more related to semi-permanent occupations where domestic and herding activities were performed. Cemeteries are also present (Tulan 58). All of them are located on the southern edge of the ravine. Evidence of the ecological complementarity within the different altitudinal zones is reflected in the spatial spread of the sites and also in material that comes from different ecological belts. The main settlements are present at around 3000masl. In this ravine, the Formative achievements are related to the onset of more humid conditions around 3000BP/1000BC and the ecological stability that this ecosystem would provide. The settlement pattern is described as dynamic sedentism (Olivera 1998), with residential agglomeration and mobility reduction. The economic, cultural and social platform of Tilocalar developments have their precedents in complex hunter gatherers from the Late Archaic, Tulan-Puripica phase, well represented in Tulan 52 (Núñez 1992; 1994; Núñez *et al.* 2006). Núñez *et al.* (2006; 2009) support the interpretation that the Tilocalar period is

characterised by a consolidation of mixed subsistence strategies, with specialisation in camelids, intense hunting complemented by gathering, miner-metallurgic activities, and to a lesser extent horticulture. Ideological changes are seen in rock art (from Kalina to Taira-Tulan style) and the ceremonial site of Tulan 54. Within this context there is an increasing and wider exchange between the Pacific Coast and the tras-Andean localities supported by the already settled caravan system. Evidences of this wide and intense interaction is reflected in marine shells, obsidian and plants from North-western Argentina and tropical snails (*Strophocheilus oblongus*), among others. Also the pottery presents the same style as El Loa Medio, Vilama and San Pedro oases sites, as well as with Northwestern Argentina. The lithic industry is now focused on copper bead production, diminishing the technology required for hunting (points, slaughter artefacts). Conical mortars are replaced by flat mortars and lithic hoes make their appearance. Archaeofaunal analyses have shown that wild camelids predominate, though domestic ones are also present in minor proportions. Cultivars are rarely present, even though horticulture in the riverbed has been proposed as well as the possibility that this was performed in the oases of Tilomonte but that the evidence has been swept away due to the instability of the soil and the continuous flow of the stream into it. Therefore hunting gathering as well as herding practices would prevail among agricultural activities in Tulan.

12. Tulan 122

Sampling: One flat mortar was sampled from the surface of the site (see Appendix 2).

Chronology: Late Archaic - Early Formative (4820-4520BP & 3230-2960BP cal/ 2870-2570BC and 1280-1010BC).

Site description: semi-permanent (2860 masl).

This site is formed by agglutinated and isolated structures (n=153) built from vertical flat rocks covering 15000m² (Figure 32). Some areas have diagnostic elements of the Late Archaic and Early Formative period (Puripica/Tulan and Tilocalar phase). It has scarce cultural remains in the limestone surface except for some central structures with small mounds composed of archaeological debris. The architectural pattern consists of a main circular structure surrounded by smaller ones, separated by *vanos* (passage ways) similar to

those present in Tulan 54. Cultural materials are characterised by lithic debris, micro-drills, copper beads, marine shells, pottery, feathers, camelid and rodent bones, textiles, pigments and archaeobotanical specimens, which are local, except for a Rhamnaceae sepal which could have been brought from Northwestern Argentina (McRostie 2004). Rinds of *Lagenaria* sp. as well as conical, flat and transitional grinding stones are abundant (Núñez *et al.* 2002-2005).

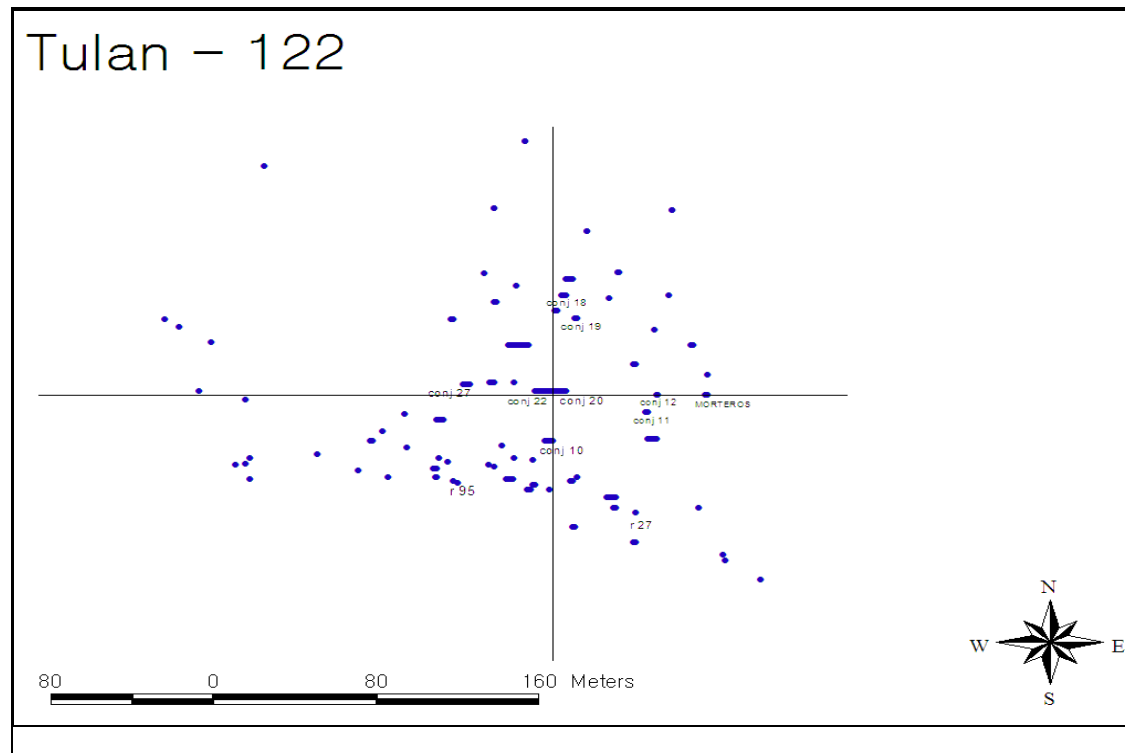


Figure 32. Plan view Tulan 122, residential structures. Courtesy of F. Gutierrez.

13. Tulan 54

Sampling: Eight grinding tools and four newborns were sampled for $\delta^{13}\text{C}_{\text{col}}$, $\delta^{13}\text{C}_{\text{ap}}$, $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ isotopes. All of them in museum premises (see Appendix 2).

Chronology: Early Formative (2320-3450BP /1400-400BC)

Site description: Permanent (habitation/ritual) (2952masl).

Tulan 54 has a complex architectural pattern. It has several areas, highlighting in the centre a large temple and in the surroundings potential habitational structures, which pre-date the

construction of the temple. To the south, a cemetery has been found (Tulan 58). The large number and density of archaeological features include a two-meter mound of 2700m² (Figure 33). Among the diagnostic and representative features of this domestic/ceremonial site are twenty-seven newborn (0-12 month) burials that were interred with wealth trade items brought from Northwestern Argentina, the Pacific Ocean and from local production. The differences in these burial offerings could reflect certain hierarchisation. Faunal remains are mainly from wild camelids and to lesser extent domestic ones. Coprolites *in situ* have been considered as evidence of slaughtering within the site. Rodents and birds are also present. Archaeobotanical macro-remains are abundant. The taxa are mainly from local species and some crops, such as *Opuntia* seeds, *Scirpus*, rinds of *Lagenaria* sp., seeds cf. *Chenopodium* sp. and cf. *Zea mays* starch grains and other microfossils that remain unidentified (McRostie 2007). Lithic categories are represented primarily by a large number of microdrills and malaquita beads, knives, scrapers and projectile points. Pottery is abundant, with the predominating forms being homogenous and suitable for cooking and drinking. The activities in the temple might have been related to a ritual filiation and ceremonial convergences where people eat, drink and feast, and remember the foundational origins of the newborns under their feet. This is the only site with these characteristics in northern Chile. Similarities are found with Chiripa and Wankarani in the highlands of Bolivia, where temples covered in debris as well as child burials with offerings have been found (Núñez *et al.* 2006).



Figure 33. Tulan 54 Temple. In the sterile floor are visible the holes for the newborn burials. Reproduced from Núñez *et al.* (2002-2005).

14. Tulan 58

Sampling: Four individuals were sampled for $\delta^{13}\text{C}_{\text{col}}$, $\delta^{13}\text{C}_{\text{ap}}$ and $\delta^{15}\text{N}$ isotopes and two individuals for $^{87}\text{Sr}/^{86}\text{Sr}$. All of them were available in museum premises (see Appendix 2).

Chronology: Late Formative (2350-2130BP/400-180BC)

Site description: Cemetery.

This is the only cemetery found in the ravine. It has an area of around 400m² and is located around 50 metres immediately to the southeast of Tulan 54. Only 8m² have been dug, in which six adults were found, in a position that recalls Late Archaic tradition (dorsal decubitus with flexed extremities), with lithic artefacts and beads as offerings. Another adult has a position more related to Formative burials of the San Pedro de Atacama oases (Figure 34). A newborn child with a feline microlithic sculpture in the mouth and a collar with more than 400 beads was also found.



Figure 34. Types of burial at Tulan 58. Reproduced from (Núñez *et al.* 2006, 108).

The coexistence of these two traditions in one cemetery has been interpreted as a transitional event between Late Archaic and Formative traditions. The dates of this cemetery are contemporary with the end of the Tilocalar phase.

15. Tulan 55

Sampling: One hoe was sampled from the museum premises (see Appendix 2).

Chronology: Early Formative (range between 3340-2540BPcal /1120-380BC).

Site description: Semi-permanent (2900masl).

This cave is a wide shelter of 7x10m, with multiple occupations through the Early Formative until the Late Intermediate period. Rock art and abundant cultural materials have been recovered. Within the undisturbed lower strata, lithic artefacts, microdrills, hoes, flat mortars, *manos*, projectile points, copper, beads, tropical snails and feathers have been found, as well as marine shells, pottery, domestic and wild camelids and their derivatives (e.g. leather, worked bone, dung, yarns), indicating a strong emphasis on herding activities. A compact floor at the beginning of the occupation has been interpreted as a corral. Archaeobotanical macroremains showed wild and domestic resources like *Zea mays*, *Cucuritaceae* seeds, *Prosopis* sp., *Geoffroea* sp., tubers, *Scirpus* roots, *Opuntia* sp., *Cortadera*

sp., *Festuca sp.* y *Stipa sp* (Popper 1987 cited in Núñez et al 2006). In my earlier analysis of one of the two hoes recovered, tuber-type starch grains were found (McRostie 2007), though its chronology is not accurate because sub-actal occupations have disturbed the initial layers and might affect layer III, where these remains were found (Núñez *et al.* 2006).

16. Tulan 67

Sampling: One lithic hoe from the Formative phase was sampled from the museum premises (see Appendix 2).

Chronology: Archaic and Formative sequence

Site description: transitory (2600 masl)

This cave has a sequence from the Early Archaic to the Early Formative as well as more recent 'modern' reoccupations. It has been related to hunting and herding activities. It also presents rock art and a lithic workshop in the outside area. Mainly wild macroremains of plants have been found, such as *Prosopis sp.*, *Geoffroea decorticans* and domestic species such as *Zea mays* and *Phaseolus sp.* for the Formative period, although the taxonomical accuracy for *Phaseolus* requires a re-evaluation.

17. Tulan 57

Sampling: Three *manos* and four hoes were sampled from the museum premises (see Appendix 2).

Chronology: Late Formative (30±80 to ca 400AD/ 1920-1550BP)

Site description: semi-permanent (2958 masl)

This camp is the closest to the origin point of the water springs of the ravine. It is an agglomerate settlement with thirteen circular mud and stone structures of large dimensions with habitational and storage functions (640m²) (Figure 35). Its architectural pattern resembles the Tulor 1 site. At the surface, there are scarce cultural materials such as lithic debris, preforms and conical and flat mortars. Excavations showed five strata to a depth of 100cms from which different materials allow us to relate this site mainly with livestock and

mining activities, though during the later occupations it seems that herding activities diminish, giving more importance to agricultural activities sustained in the Tilomonte oases. This site is linked to the Late Formative. Evidence of this occupation includes mature camelids and their derivatives, such as leather, dung and yarns; diagnostic pottery of the period mainly for cooking activities, flat and conical mortars, projectile points, knives, scrapers, abundant red pigment, shells from the Pacific ocean as well as from the eastern Yungas; melted copper and lithic hoes, which have been related with canalisation work, mining and horticultural activities in the small patches of the gorge. In this case, Núñez proposes that hoes in disuse would serve as platforms for multiple purposes. Finally *Opuntia* sp. and *Geoffroea decorticans* have been found.

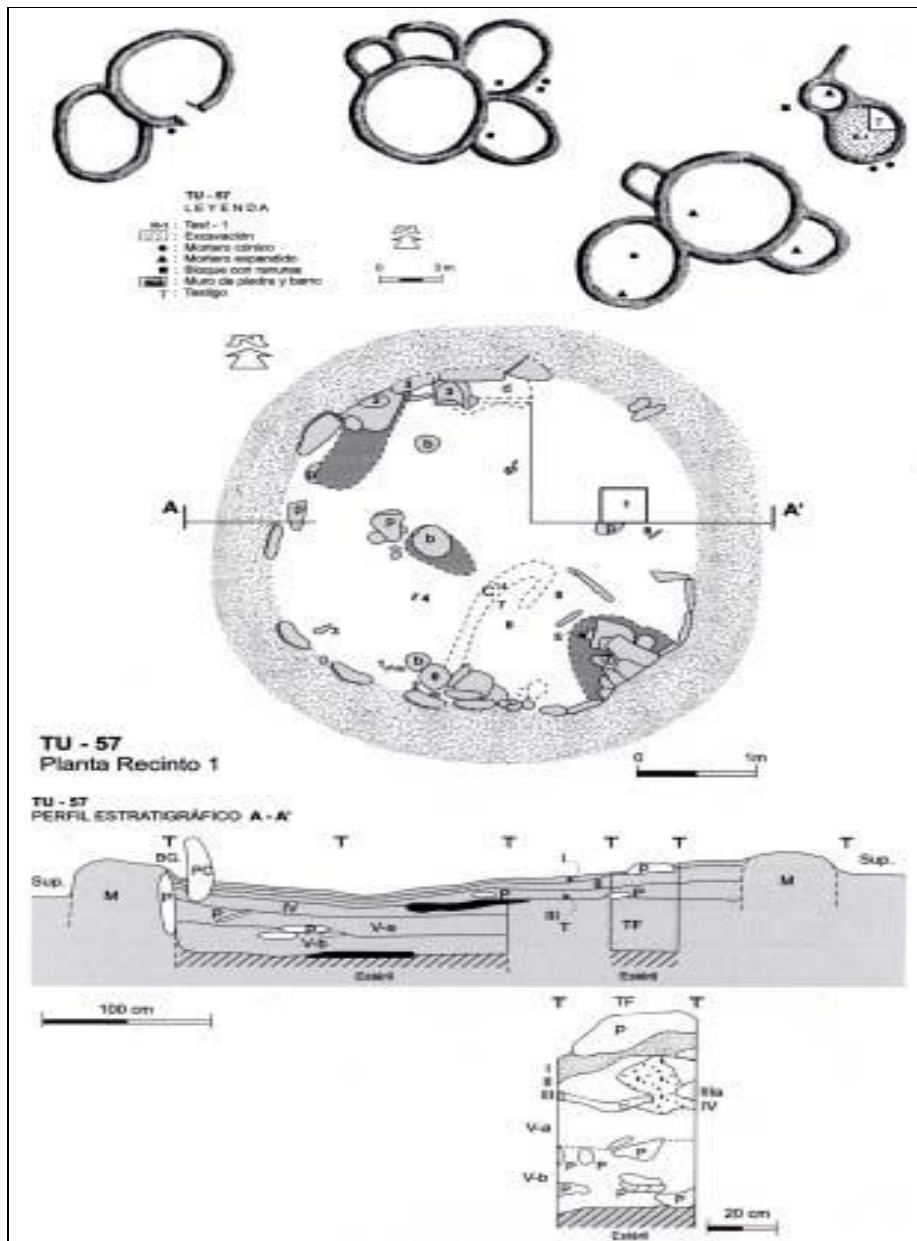


Figure 35. Plan of Tulan 57 village. Reproduced from Núñez (2005, 107).

18. Tulan 82

Sampling: One *mano* was sampled from the museum premises (see Appendix 2).

Chronology: Late Formative (ca. 1610BP- 340AD)

Site description: semi-permanent (2380masl)

This site is located on the border of the Salar de Atacama near the Tilocalar meadows. It is made up of forty-nine residential and storage structures covering around 800m² (Figure 36).

It has been related mainly to herding activities. Habitation as well as mining activities are evident on the surface. The Tulor pattern on the architecture is also present here. Grinding tools, lithic hoes, projectile points, camelid bones, textiles, yarns, ropes, coprolites, leather and llama hooves are indicative of herding management. *Zea mays*, *Prosopis* sp. and *Geoffroea decorticans* may have been brought from Tilomonte oases, as this environment is too salty to cultivate plants but fertile in grassland for livestock.

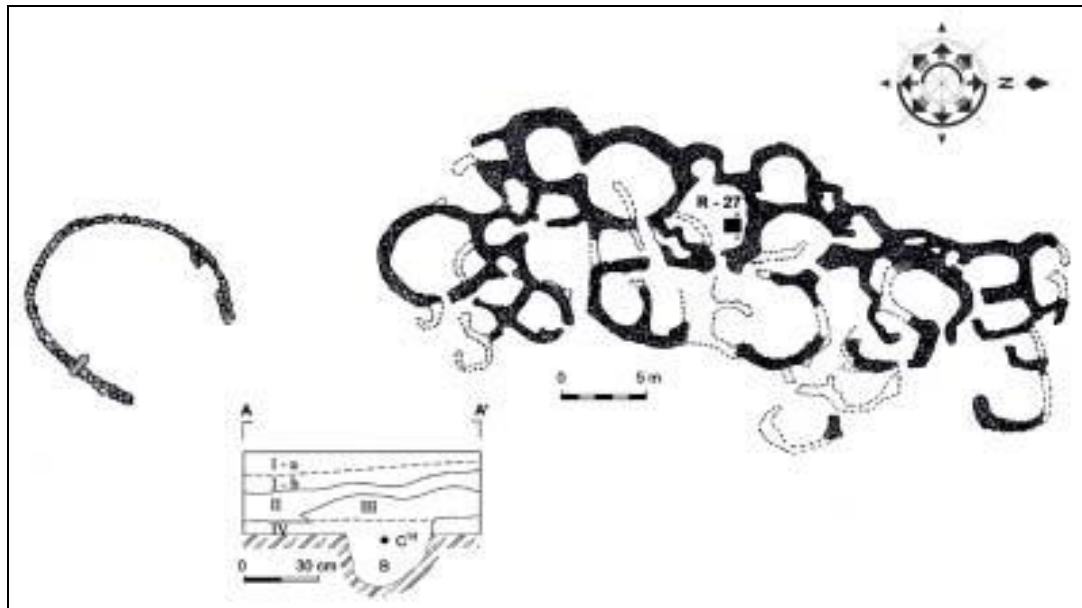


Figure 36. Plan of Tulan 82 village. Reproduced from Núñez (2005, 186).

19. Tulan 85

Sampling: Nine mortars and one *mano* were sampled from the surface of the site (see Appendix 2).

Chronology: Early and Late Formative (3480-1520BPcal/ 1530BC-430AD)

Site description: Permanent (2380 masl)

Tulan 85 shares some characteristics with Tulan 54, though it does not have the rituality and monumentality of the latter. It is located at the western edge of the Tulan gorge at the edge of Salar de Atacama near the Tilocalar meadows. Similar to Tulan 54, this site is a monticule two meters deep and with an area of 2500m² made up of cultural debris, especially layers of plants, ashes and dung with camelid bones in between, which represent wild and domestic specimens (vicuña/guanaco-llama). The lithic is represented by microdrills, projectile points,

knives and scrapers, conical and to a lesser extent flat mortars. Pottery is also abundant. Archaeobotanical analyses has identified a large number of local plants, such as *Atriplex* sp., *Tessaria absinthioides*, *Ephedra breana*, *Distichlis spicata* and *Scirpus* sp. (Bueno 2003; McRostie 2008). *Zea mays* cobs have been found dated at 760BC. Also, four newborns have been found, though without the rich offerings found in Tulan 54. The main mound is well dated through the Tilocalar or Early Formative phase, whilst the surrounding structures are dated to around 300AD (Cartajena & Carrasco 2009) and therefore the samples from this site are ascribed to the Formative period rather than to a specific phase.

This site has been related mainly with pastoralist activities due to its location near the Tilocalar vegas where *Lama* graze (Labarca 2005). The salty environment of the location excludes any possibility of agricultural activities.

Summary

The choice of sites and the sampling of materials presented above has been selected to include some of the most “representative” sites discussed in the literature for the periods and areas (see CH. III) and to provide study material that covers the transition from late Archaic to Late Formative periods in a wide part of the Atacama region. This representativeness is also achieved by focusing on some of the most diagnostic artefacts of the periods that I am interested in sampling, such as grinding tools and hoes. The preliminary archive research, application for permits, fieldwork, museum work, and sampling for this thesis has been time consuming, but, I am aware that there is a whole range of other sites that could be integrated into the discussion in order to gain a deeper perspective of the results and that other sites as well as other materials (e.g. pottery) should be sampled in future analyses. Also, the precise contexts from which some artefacts were recovered are not clear due to the lack of labels or detailed field notes that describe the function and characteristics of the structures, and in some cases where the stone tools were not retrieved during excavation I sampled these at the sites themselves; therefore, artefacts and their microfossils are discussed as representative of the site and period but not of specific archaeological contexts. The results obtained from these samples cannot be fully

conclusive, but they will serve as a first approach to the methodological and theoretical problems formulated in this thesis.

For the Late Archaic period, just three main campsites were sampled for residue analyses (Kalina, Ghatchi and Puripica 1). This serves to complement previous analyses made in Tulan 52 (McRostie 2007). During the Early Formative period, the available materials are present just in sites from the rivers and ravines of the Salar de Atacama. Ghatchi and Tulan 55, 85 and 122 were sampled for residue analyses, whilst isotopes were considered for Tulan 54 and 58. For the Loa, both analyses were performed respectively from the habitation site Chiu Chiu 200 and from Chorrillos cemetery.

During the Middle and Late Formative period of the oases (which correspond to the Late Formative period of Tulan), the main sites are present in the ravines (Ghatchi and Calar) and in the oases in just one habitational site (Tulor 1). Much of the prehistory of this period and area has been based on this site, and therefore there are hypothesis and models that are worthwhile to evaluate. The same happens with Toconao Oriente, which has also been crystallised as representative of the Formative populations in the oases. Both sites have been sampled for residue analyses and isotopes respectively. Hence, most of the data for residue analyses during the Late Formative in the Salar de Atacama comes from the ravines (Puripica 23, 31, Calar, Ghatchi, Tulan 57) and some from meadows in the Salar de Atacama (Tulan 82, 85), whilst Calar was sampled for isotopes.

For the Late Formative of the Middle Loa, fewer sites were available for sampling in museum devices, and therefore only Ranl 273A was sampled for residue analyses.

CHAPTER VII. METHODOLOGY

Introduction

The first section of this chapter refers to the microfossil methodology regarding the reference collection and archaeological samples. Taphonomical issues regarding the systemic and archaeological context are also discussed. The second part refers to the principles of isotope analysis and the approaches that I will use for interpreting my data. Here I will also present the process of developing a reference collection for the microfossil analysis and archaeological samples taken to provide a base line for the isotope analysis.

VII.1 Microfossil reference collection, archaeological sampling and microfossil characterization

Microfossil reference collection

A microfossil reference collection of phytoliths, calcium oxalate and starch grains from the wild plants and Andean crops used in the area was created by collecting and preparing samples from modern specimens that could then be used as a comparative base to identify the archaeological specimens (Appendix 3). For Andean wild plants, previous microfossil characterisations were also considered (Babot 2004; Giovannetti *et al.* 2008; Korstanje 2005; Korstanje & Babot 2007; Logan 2006). In addition, I accounted for other researchers' indexes of South/American crops (e.g. Babot 2003; Babot 2004; Bozarth 1996; Cortella & Pochettino 1994; 1995; Korstanje 2001a; Korstanje & Babot 2007; Logan 2006; Mulholland 1993; Pagán-Jiménez 2007; Pearsall 1978; Pearsall *et al.* 2003; Pearsall & Piperno 1990; Piperno 1984; Piperno *et al.* 2009). Also, local crops were sampled to assess potential diversity. A local reference collection was used as the main guideline for wild and domestic plants.

- Starch grain references were collected by mounting a fresh-pounded fragment of the plant on a slide with glycerol. Experiments show that glycerol has no effect on archaeological starch and is an appropriate medium for semi-permanent slides (Perry 2004). These tissues were centrifuged and/or sieved when visibility was poor (Giovannetti *et al.* 2008). One drop

of the sample was mounted and the cover slip was sealed with nail polish. The whole slide (20x24mm) was scanned at 20x with and without polarised light. Pictures and characterisation were made at 40x, following Pagan-Jiménez's (2007) morphological key, which was modified when necessary (Appendix 4). The descriptions were mainly centred on the form, presence or absence of lamellae, visibility and location of the hilum, the characteristics of the extinction cross, presence or absence of internal fissuring and size. Subsequently, SPSS software was used to obtain the descriptive statistics for the variants of each taxon.

- Phytoliths from different organs (stem, husk, leaf and inflorescence) of wild and local crops were analysed. Wild grasses present in the area were sampled to find possible maize confusers (e.g. phytoliths from other plants that are sufficiently similar to those from maize plants that they could easily be mis-identified). The plants were prepared by dry ashing and processed following Korstanje's (2005, 142) protocol. One drop was mounted on glycerol and the slide was entirely scanned (20x24mm) at 20x, changing to 40x to analyze each microfossil. The data was standardised with a counting form based on anatomical and morphological criteria following the ICPN code and other descriptions (see Appendix 3). Nominal abundance was used: (a) abundant, one or more in each image field; (b) common, one or more in each slide transect; (c) rare, in the order of one to three in each slide (Iriarte & Paz 2009).

- Calcium oxalate crystals. The same plants were used as for the reference collection for phytoliths. The most commonly encountered forms of calcium oxalate crystal are (1) the raphide, a needle-shaped crystal occurring in bundles of many crystals per cell; (2) the styloid, an elongated crystal with pointed or ridged ends; (3) variously shaped prisms; (4) crystal sand, a mass of many tiny, individual crystals in a single cell; and (5) the druse, a spherical aggregate of individual crystals. Other shapes appear to be variations of these forms (Franceschi & Horner 1980, 381).

Archaeological artefacts and sampling

Artefacts that historically have been assumed to be agricultural and/or plant processing tools (lithic hoes, *manos* and mortars) were sampled for complete analyses of microfossils

(Babot 2004; Boyd 1998; Campos *et al.* 2001; Coil *et al.* 2003; Iriarte *et al.* 2001; Korstanje 2005). This analysis has the advantage of complementing different microfossils in order to achieve taxonomic identification, though samples can be less clear than when using a traditional protocol which involves acids and/or chemical substances. Microfossils include starch grains, phytoliths and calcium oxalates, which can have a taxonomical value alone or in conjunction¹⁰. Also pollen, spherulites and biological organisms such as diatoms will be considered when present in the archaeological sample (Coil *et al.* 2003).

The samples of the residue from grinding stones, *manos* and hoes were taken mainly from museum collections, although some grinding tools were sampled from the surface of the sites¹¹. This sampling represents almost all the sites with available artefacts related to plant processing from the Late Archaic and Formative sites of the studied area. The samples comes from eighteen sites that represent the Late Archaic and Formative periods in the western slope of the Puna de Atacama, four sites in the Middle Loa (Chorrillos, Chiu Chiu 200, Ranl 273, Kalina) and fourteen from the Salar de Atacama area (Ghatchi 2C, Calar, Puripica 1, Puripica 23, Puripica 31, Tulor 1, Tulan 54, 55, 57, 58, 67, 82, 85, 122). The sampling was made from ninety-eight grinding tools; forty-seven mortars (forty-eight samples), fifty-one *manos* (fifty-two samples) and fifty-two hoes (sixty-five samples) (total 150 artefacts and 165 samples). For the Late Archaic, I sampled twenty-eight artefacts (six *manos* and twenty-two mortars) from three sites (Kalina, Ghatchi 2C and Puripica 1). These three sites are located in riverine/ravine platforms. The artefacts are exhausted conical mortars and *manos*, whose residues were collected *in situ*, except for Puripica 1. For the Formative period, thirty-one artefacts were sampled (fourteen hoes, three *manos* and fourteen mortars). These sites (Chorrillos, Ghatchi 2C, Tulan 67, Tulan 85) cover the whole sequence of the Formative, so the samples are not representative of any specific phase. For

¹⁰ Hather (2000) argues that calcium oxalate crystals are of no diagnostic value. If they are, they are only in the very broadest terms (perhaps to exclude certain redundant identifications in conjunction with other data).

¹¹ In Ghatchi and Kalina mortars are still *in situ*. The isolation of the sites allows suggesting they have not been manipulated after their archaeological use.

the Early Formative, twenty-eight artefacts were sampled (nine mortars, eleven *manos* and eight hoes) from four sites (Chiu Chiu 200, Tulan 54, Tulan 55, Tulan 122). For the Late Formative, sixty-three artefacts were sampled (thirty-two *manos*, two mortars and twenty-nine hoes) from eight sites (Ranl 273, Tulor 1, Pu-23, Pu 31, Calar, Tulan 57, Tulan 58, Tulan 82) (Table 27).

PERIOD	SITE	mano	mortar	shovel	Grand Total
L.A	Ghatchi 2C	3	12		15
	Kalina	2	10		12
	Puripica 1	1			1
L.A Total		6	22		28
E.F	Tulan 55			1	1
	Chiu Chiu 200	8	3	7	18
	Tulan 54	3	5		8
	Tulan 122		1		1
E.F Total		11	9	8	28
L.F	Puripica 31	5		4	9
	Puripica 23	2		5	7
	Calar	2		6	8
	RanL 273	4	2	2	8
	Tulan 57	3		4	7
	Tulan 58	1			1
	Tulor 1	13		9	22
	Tulan 82	1			1
L.F Total		31	2	30	63
F	Ghatchi 2C	2	5		7
	Tulan 67			1	1
	Tulan 85	1	9		10
	Chorrillos			13	13
F Total		3	14	14	31
Grand Total		51	47	52	150

Table 27. Sites and artefacts sampled (LA: Late Archaic, E.F: Early Formative; L.F: Late Formative; F: Formative -represents all the Formative sub-periods-).

As we can see (Figure 37), the proportions of artefacts sampled for each period and site is uneven and these frequencies were determined mostly by logistical reasons: hence, when possible, I tried to sample the majority of the tools available instead of standardizing frequencies between sites and periods.

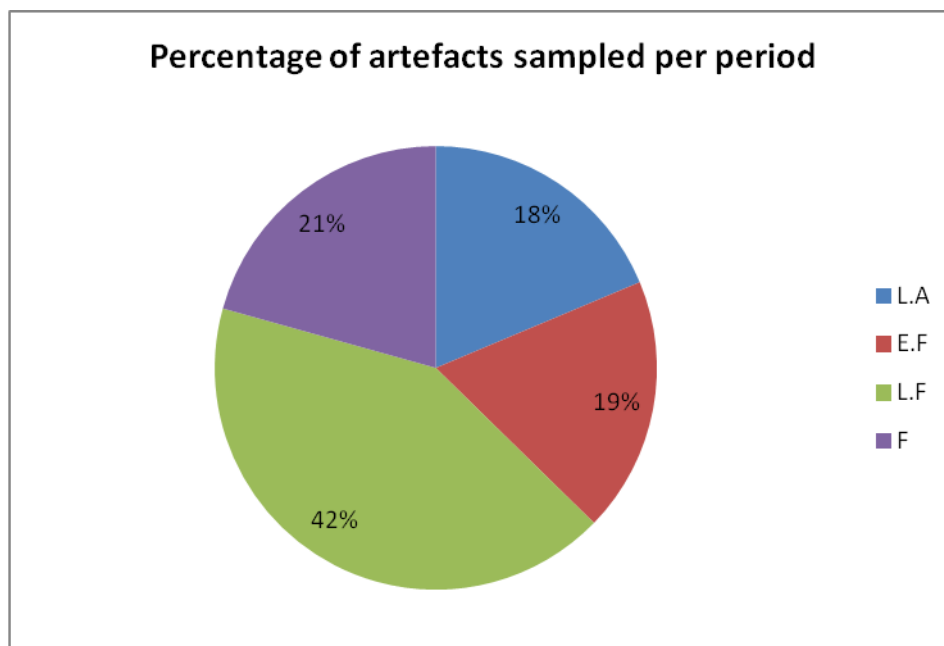


Figure 37. Distribution of artefacts sampled per period (LA: Late Archaic, E.F: Early Formative; L.F: Late Formative; F: Formative -represents all the Formative sub-periods-).

However, proportions of types artefacts sampled were almost equal (Figure 38).

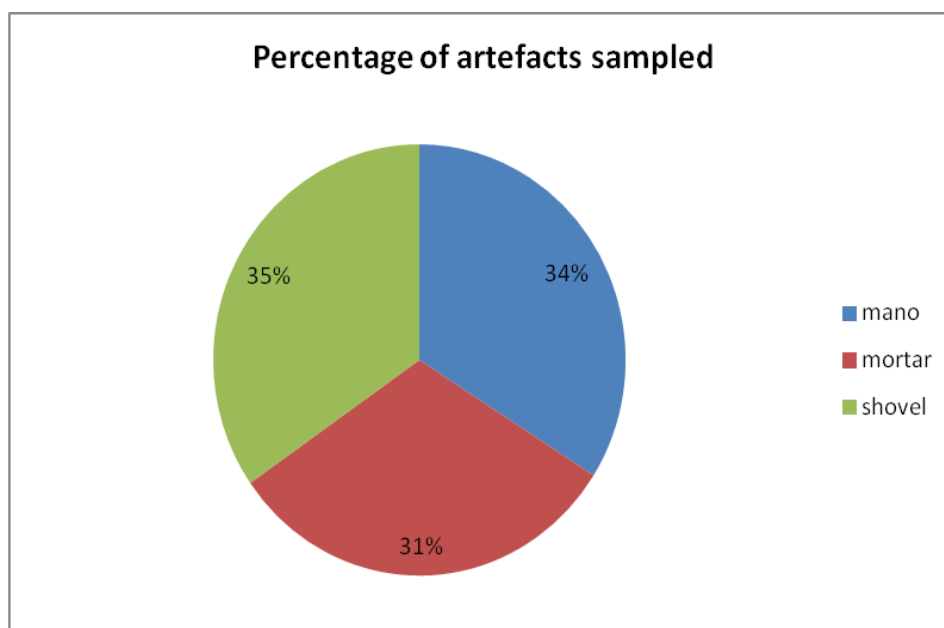


Figure 38. Distribution of types of artefacts sampled.

Before each sampling, the area and devices used were carefully cleaned with chlorine. Dust on the surface of the artefact was blown with a nasal aspirator. As most of the tools were kept in museums or were located in low erosion surfaces, they did not have large amounts

of sediment attached; for those that did, this sediment was saved to evaluate contamination (S1). Afterwards, the hollows and cavities in different areas of the tool were scraped with a clean needle. I did not assume differences between areas of the tool due to taphonomical variables and the fact that residue types are not strictly confined to the working edge (Babot 2004). The latter sediment (S2) was saved in eppendorf tubes. One drop of sediment (1 and 2) was mounted with glycerol and the slide was entirely scanned (using a 24x20mm cover-slip).

Archaeological microfossils

Microfossils (starches, phytoliths and calcium oxalates) were characterised following the reference collection criteria. Identification of taxa was achieved when possible, relying either on one type or multiple types of microfossils to cross-check the identification. For residue analyses obtained from artefacts, these cannot be subjected to statistical treatment because the identifications start from a reduced number of particles, which then become an even smaller number of taxonomically diagnostic particles (Babot 2004, 207). Hence the presence/absence of identified microfossils and/or taxa on the artefact was used as a measurement of abundance.

Regarding starch classification, the discrimination and correlation of selected morphological variants was used to achieve different taxonomical or similarity levels. The most relevant variants considered were form, presence or absence of lamellae, visibility and location of the hilum, the characteristics of the extinction cross, presence or absence of internal fissuring and size. The positive presence of starch grains was assessed by rotating the polarising plates on the grain in which the arms of the extinction cross rotate radially around the central crossing point (Loy 1994, 98). The assignment of the archaeological granules to a plant taxon was based mainly on the local reference collection, following the premise that most starches might be identified to species if the comparative collection of the researcher contains all necessary congeners (Perry 2004). Nevertheless, due to redundancy or the lack of some variants in archaeological granules, a conservative approach was used: this means that “if the characteristics of the starch granule in question deviated from any source, published or otherwise, the identification was not secured” (Perry 2004, 1076).

Phytoliths were rotated and classified according to anatomical/morphological categories from the ICPN code and other authors (see Appendix 3 and CH. VIII). These variants were compared against the reference collection and pertinent literature. Spherulites were attributed to camelids/non camelids (Korstanje 2005) and diatoms were used just as indicators of humidity due to the precarious information of their taxonomy in the region. Pollen was identified to general levels following Heusser's (1971) manual.

Taphonomical issues

One of the main purposes of taphonomical studies is the understanding of possible biases in the fossil record. These biases can be either part of pre- or post-depositional processes and human or non-human induced (Madella & Lancelotti 2011). Hence, following Schiffer (1972), I recognise two different types of context: systemic context and archaeological context. The former refers to the living society that artefacts and features were once a part of, while archaeological context refers to the distorted remains that the archaeologist finds during excavation. Within these contexts, there are two types of formation process: cultural formation and non-cultural formation. Cultural formation processes are the result of human actions, whilst non-cultural formation processes are the result of natural phenomena (Schiffer 1983).

For the sites analyzed here, there is no information about reoccupation of the original systemic context, so the major cultural processes affecting the archaeological contexts are excavation and manipulation in the museum devices, although within the systemic and archaeological contexts, different natural variables might have affected the deposition and preservation of microfossils.

Archaeological context: cultural formation process

Regarding the tools sampled, most of the sites from which they come were excavated from the 1980s onwards. Unfortunately, some of the artefacts are not properly labelled, in most of the cases there is no available soil from corresponding strata and gloves with maize starch has been used at least in the last few years at Gustavo Le Paige, San Pedro museum¹². These and other contamination variables are hard to track due to the lack of proper informants and diaries related to the excavations and post-excavation handling. However, even if new excavations were done, it is not certain that these types of tools would be recovered again in large amounts; therefore, the artefacts sampled here reflect the main bulk of this universe for the periods and areas of interest. To minimise the possible biases produced by the contamination at the museum premises, the history of tool deposition was tracked as much as possible (Appendix 2). The gloves with starch used in San Pedro museum were sampled to compare them with archaeological starch grains (Appendix 3) and an experiment was conducted that involved handling stone fragments (more/less porous) with the gloves to replicate the manipulation they might have undergone in the museum and its consequences in terms of contamination (Appendix 5). This experiment throw different frequencies of starch grains attached to the tools as well different combination of variants in the starches attached to the gloves. However, these latter were possible to be differentiated from the archaeological starches. Other studies recording gloves with starch grains conclude that residue distribution patterns of some contaminants can potentially be recognised (Wadley & Lombard 2007).

Another taphonomical variable is the damage or alteration in the microfossil assemblage due to laboratory protocols and manipulation (Coil *et al.* 2003; Madella & Lancelotti 2011; Strömberg 2007). Nevertheless, this stage will not be discussed here, as no lab processing was used for the archaeological samples and therefore their damage was reduced to a minimum (Babot 2004).

¹² See Appendix 2 for context descriptions and artefact images

Regarding contamination while analysing the samples, numerous slides were put in different areas of the office where microscopic analysis was carried out in the Institute of Archaeology, UCL, in order to track whether some microfossils could be floating around. Fortunately, these slides just had some dust on them by the end of the slide analyses (approximately twelve months). Wadley *et al.* (2004) also found just dust in control slides.

Archaeological and systemic contexts: natural formation process

Actual flora and macrofossil flora from the archaeological sites are considered as potential microfossil producers (Babot 2004). In this regard, the reference collection as well as the documentation of the current flora at the sites (Chapter III and VI) should be useful to track potential contamination from microfossils coming from the local vegetation. Regarding taphonomical variables that might affect organic and inorganic microfossils at the sites and their attachment to tools, these are discussed below based on different experiments.

- Organic particles:

Starches have been found in different environments and have shown that they can survive for millennia. On one hand, some authors defend the systemic context of starches found on artefacts. Therin (1998) and Haslam (2009) have shown that starches do not move greatly within the soil matrix. From this perspective, the frequency of starch grains might be strongly correlated with used artefacts and not correlated with unused artefacts or sediments. Loy *et al.* (1992) found no starch present in the matrix of the artefacts. They also noticed a differential distribution and frequency pattern of starch grains between those tools with direct and indirect plant manipulation. Atchison and Fullagar (1998) used differences in starches recovered from artefacts and associated sediments to rule out contamination. Controlled experiments have placed clean and recently used artefacts in direct contact with different organic materials, finding out that even if there might be some residue transference, starch grains do not “jump” from the surrounding soils to the nearby artefact (Williamson 2006). Hart (2011) also shows that residues from surrounding soils do not penetrate into the pores and crevices of the artefacts. Langejans (2010) demonstrates that the numbers of non-use-related residues are considerably smaller than those of use-related residues on tools, and they also present a random distribution in the artefact.

Wadley and Lombard (2007) have noted that use-related residues are generally present in larger quantities than contaminants which occur as isolated residues. Regarding starches in plants, Pagán-Jiménez (2007) states that starches are not released from the cellular tissues unless friction is applied. If the starch grains are relieved naturally in the soil, these are usually those transient forms which are formed in non-storage organs (leaf, bark, stem) and which are small and non-diagnostic (less 5µm). But those from storage organs such as fruits, tubers and seeds will be used as energy either to get to their maturation stage or to germinate using these nutrients before they decay (Pagán-Jiménez 2007). In this sense, it is unlikely that diagnostic starches in sediment would survive before attaching to artefacts, the correspondence between starch grains and tools being exceptional in comparison with other microfossils (Pagán-Jiménez 2007). Liu *et al.* (2011) also show that archaeological artefacts concentrate the main bulk of starches in comparison to their soil matrix. "This phenomenon suggests that starch grains recovered from these tools are associated with tool use rather than from the enclosing soil matrix" (Liu *et al.* 2011, 5).

On the other hand, several authors have questioned whether the absence of starches in the matrix surrounding the artefacts is sufficient evidence of the archaeological nature of the microfossils attached to the tools. The nature of preservation of starches in soil v/s artefact fissures is still uncertain, as are the factors involved in post-deposition decomposition of organic residues (Grace 1996; Haslam 2004; Perry 2007; Therin *et al.* 1999). Although it seems that artefacts provide a protective microenvironment for starches and other microfossils (Field & Fullagar 1998; Haslam 2004; Pearsall *et al.* 2004; Perry 2004; Piperno & Holst 1998). Haslam has argued that starch grains found in artefacts could be either due to authentic contact-residue (from use or incidental contact) or sediment transfer within the first months of deposition (Haslam 2004). Wadley *et al.* (2004) found that in rich organic soil (e.g. commercial compost), contamination with plant residues is a real threat.

Considering the variables that might affect the preservation of organic remains in soils, Langejans (2010, 972) summarises some that generally stop biological decay:

1. Oxygen free;
2. Water free;

3. Extreme pH values, particularly low values, hinder biological decay (for example in bogs);
4. Moderate pH values impede chemical weathering;
5. Low to extremely low temperatures;
6. Nutrient or cation depleted;
7. Anti-bacterial; can be extremely salty (extreme pH) or in the presence of metals;
8. Stable, non-erosive.

He tests these variables in three different settings, concluding that dry conditions are an important factor in preservation, as well as protected micro-environments such as pots, within the matrix of pottery sherds and grindstones. In this sense, tools from stable sites with no, or low, bioactivity (such as the dry conditions of the Atacama) are best for residue analyses. Babot and Bru de Labanda (2005) evaluate three variables of starch preservation in archaeological artefacts: location of the artefact (surface/subsurface); position of the artefact (upside, down, lateral); and texture of the rock. Their results show that independently of these variables, the tendency for starch preservation on artefacts is limited, the likelihood of finding microfossils is co-variant with the position and texture of the rock and finally that starch grains have important potential for preservation, especially in non-aggressive environments such as the highland desert of Northwestern Argentina as opposed to sub-tropical environments (Lu 2003). A similar experiment left exposed and buried tools in an open field for two years on Warkworth, UK (Barton 2009). The results showed that starch persists in tools and that physical conditions are similar to those that starches encountered in archaeological contexts. However, contrary to Langejans (2010), Barton found that the survival of starches was greater in surface artefacts. Therefore, it is not rapid burial that might protect the particles but other variables such as quick drying of the residue, which might form a hard plaque that is relatively hydrophobic and resistant to microbial attacks. This result confirms previous studies (Barton 2007; Barton & Matthews 2006; Gurfinkel & Franklin 1988; Loy 1987).

In any case, the sample observed by the archaeologist is not the original sample. Starch follows an asymptotic curve, with rapid initial decay and then an exponential fall-off rate of

decay thereafter (Haslam 2004; Langejans 2010). Therefore, starches found by the archaeologist are leftovers of a major universe in which their relevance is hard to judge and acknowledge. However although only a proportion of the original starch grains may survive in an identifiable form, the majority of the studies above support the conclusion that starch grains adhering to stone tools are most likely to be residues from the active use of those tools and are much less likely to be contamination from the burial environment.

- Inorganic particles:

Phytoliths, pollen and diatoms have differential nature of production, deposition and preservation. Pollen is a reproductive structure designed to disperse via wind, animals or water. Depending on the taxa and natural agents, it can reflect local, extra-local or regional vegetation. Its preservation in soils is affected by complex factors, which are usually grouped into three main categories: (1) mechanical, (2) chemical, and (3) biological (Bryant & Holloway 1983). Due to the dispersal character of pollen, its findings in archaeological artefacts require caution. For this reason, a technique known as pollen wash, designed to extract the pollen adhering to the surface of the artefacts, has been proposed (Pearsall 2000). Many studies also revise the matrix found in or adhering to these artefacts (Bohrer 1981; Bohrer & Adams 1977; Hevly 1964), though this is not as reliable as the pollen wash. For both, control of sediments is essential in addressing cultural versus natural deposition. Some examples show the potential of pollen wash to interpret the function of tools and plants used in archaeological contexts (Bohrer 1981; Hevly 1964). Also, controlled experiments have shown similar taphonomic marks in archaeological and modern pollen processed in slabs. For surface artefacts, it is hard to discriminate between modern and archaeological pollen (Bryant & Holloway 1983).

Diatoms as unicellular algae are present in different water sources. Therefore, their presence in artefacts might reflect either the use of water in the processing or post-deposition factors such as the contact of the artefact with water flows or sediments that contain these organisms.

The different processes concerning phytolith formation and post-deposition variables that affect them have been resumed in three phases (Dodd & Stanton 1990; Madella &

Lancelotti 2011; Osterrieth *et al.* 2009): 1. necrolysis, which deals with the decomposition and disaggregation of the plant at the time of death; 2. biostratinomy, which deals with all the processes that take place after the plant death but before the phytoliths' burial; and 3. fossil diagenesis, which comprises the cumulative effects of the physical, chemical and biological processes that may alter or destroy the phytolith fossil record (Osterrieth *et al.* 2009).

The first stage assesses the differential stages of silica formation in the cellular tissues, which has consequences in morphological patterns relevant for identification. The second stage implies transport and different levels of damage due to friction with the surface. Phytoliths generally reflect the *in situ* decay of a particular plant or plant formation. However, other studies demonstrate that phytoliths as pollen can be widely transported with wind (Piperno 2006c; Twiss *et al.* 1969). Fluvial action also creates a flow of soil particles and therefore a flow of phytoliths (Piperno 1993; 1995). "In general, phytoliths are not transported over long distances because they are relatively 'heavy' particles (as opposed to pollen, for instance) but there are situations in which transport can be an important factor in the making of an assemblage. This is the case of dry environments with sparse vegetation and strong winds (e.g. deserts, loess plateaus) or environments with heavy precipitations and important runoff" (Madella & Lancelotti 2011, 3). Phytoliths that are transported by wind are heavily pitted by colliding with sand and silt grains in the wind, so one can distinguish between *in situ* phytoliths and wind-blown ones in many cases (A. Rosen pers. comm. 2013). Therefore, phytoliths can represent local, extra-local and regional vegetation depending on the natural as well as cultural agents involved. The third stage supposes pedogenesis (soil formation), diagenesis (rock formation) and bioturbation. These agents might strongly affect the phytolith assemblage depending on pH, water availability, root density and temperature, among others. These effects are also influenced by the shape, surface and degree of silicification of the phytolith (Piperno 2006c). For instance, alkaline soils (with a pH over 9) might dissolve phytoliths (Cabanes *et al.* 2012; Piperno 2006c); nevertheless, some pH measurements made in the Atacama range between 7.9 and 8 (Neilson *et al.* 2012) and therefore should not represent a bias towards their preservation. Once deposited within the soil, it seems that movements are not too significant. When the

surrounding plant tissues have decayed, phytoliths chemically bind to the surrounding soil and resist horizontal and vertical movement in most soils (Chandler-Ezell & Pearsall 2003; Pearsall 2000; Piperno 2006c). Indeed, soil processing has shown that it is hard to break the chemical bonds between soil and phytoliths. This characteristic of phytolith deposition is known as the decay-in-place model (Mulholland 1989; Pearsall 2000), although if the sediment is unstable (sand/ silt), then the phytolith will be as well (Pearsall 2000).

In anthropic areas, phytolith samples might be affected by trampling, among other variables. Pearsall *et al.* (2004) have proposed that phytoliths from sediment directly associated with tools represent cultural residues, whilst the external sediment would represent the floor phytoliths. This proposition has been positively confirmed by experimental analyses conducted by Kealhofer *et al.* (1999) in which they conclude that “the phytolith assemblage composition of the artefact residue samples are distinct from the soil matrix. Therefore, we accept that the assemblages of phytoliths extracted from the artefact residue samples are related in a meaningful manner to artefact use...” (Kealhofer *et al.* 1999, 540). Bowdery (2001) also considers that differential frequencies of phytoliths and starches preserved in an obsidian tool are caused by cultural use rather than contamination from the immediate soil. Regarding preservation in artefacts, most of the phytoliths might be part of decayed plants brought to the site by people and to a lesser extent of natural surrounding vegetation (Piperno 2006c) if environmental factors do not significantly affect their transport. In general, more protected environments (e.g. caves) will allow a better preservation of those more fragile phytoliths, although most of them will preserve relatively well in open environments due to their silica structure.

Systemic context: cultural formation process

This definition allows discrimination towards economic plants used by pre-Columbian peoples. Firstly, plants that do not grow within the sites or their surroundings, have an economic value and are not suitable for wind or other natural deposition will be considered as “cultural” within the systemic context. Even if non-cultural agents such as animals could have brought bigger fruits, pods or tubers into the sites, the repetition of certain taxa and microfossils through sites and tools, cross-referenced between microfossils and with macro-

botanical remains, will be considered as an indicator of their systemic nature even if the processes of attachment to the tool are harder to discriminate as natural or cultural, based on the above discussion. Another important aspect with regard to starch grains that can also give clues about their cultural manipulation within the systemic context is the taphonomical damage (Table 28) related to culinary practices (toasting, grinding, boiling, dehydration, fermentation, etc.) (Babot 2004).

Damage and modifications in the starch grain	Dehydration by aeration	Toasted	Calcined	Freezed	No desaponification	Grounded
Fissures	x	x		x		xxx
Fractures				xxx		xxx
Hilum alterations	x	xxx		xx		xx
Depressed setoff	x	xx	xx	xxx		xxx
Low visibility	x	xx		xxx	xxx	xxx
Popped				xx		xx
Damage on the surface				x		xx
Damage on the contour				x		xx
Emptying				xx		xx
Invisibility of lamella	xx			xxx		xx
Disaggregation			xx	x		xxx
Gelatinization		xx	xxx			
Plasters		xx	xxx			
Alteration in birefringence	x	x	x	xxx		xxx
Alteration in extinction cross	x	xx	xxx	xxx		xxx
Alteration in size				xx		xxx
Alteration in size ranges				xx		xxx

Table 28. Taphonomical consequences related to culinary practices. Number of crosses is correlated with degree of damage. Reproduced from Babot (2007, 108) translated by V. McRostie.

Following Haslam (2009) and Langejans (2011), one way of achieving a cultural interpretation of the data is by analyzing relatively large tool samples of similar morphology and considering repeated patterns of microfossils to understand whether the residues are related to cultural use. Barton (2007) has shown that museum artefacts do preserve starch granules, defending this class of archive in the research of tool function and plant processing.

VII.2. Isotopes: Principles, reference collection and archaeological samples

Isotopes: principles and interpretation issues ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^{18}\text{O}$, $^{87}\text{Sr}/^{86}\text{Sr}$)

Carbon and nitrogen ratios on human bones can be used to reconstruct the pre-Columbian diet because of the differential fractionation of some plant groups of carbon dioxide during photosynthesis and nitrogen during fixation or absorption (Tykot 2004). These isotopes are fixed in the organic (collagen: $\delta^{13}\text{C}_{\text{col}}/\delta^{15}\text{N}$) and inorganic (apatite: $\delta^{13}\text{C}_{\text{ap}}$) fractions of the bones and other tissues (hair, nails), providing direct evidence of the consumption of specific types of food, and complementing other indirect sources such as zoo-archaeological and archaeobotanical evidence (Calo & Cortes 2009). Collagen and apatite are constantly being reabsorbed, so they present a picture of the last several years, though tooth enamel will reflect the diet during crown formation (Tykot 2004). To gain a better interpretation, it is recommended to combine the $\delta^{13}\text{C}_{\text{col}}$ (to determine the protein component of the diet, as it is derived from plant sources), $\delta^{13}\text{C}_{\text{ap}}$ (to determine the “whole” diet, e.g. protein, carbohydrates, lipids), $\delta^{15}\text{N}$ (to determine protein source and trophic level), and $\Delta^{13}\text{C}_{\text{ap-Ccol}}$ (to determine the degree of carnivore versus herbivore) (White *et al.* 2006). However, the extent to which this difference represents the trophic level has been questioned by some authors, as it might also be a consequence of the $\delta^{13}\text{C}$ values in protein, lipids and carbohydrates (Ambrose & Norr 1993).

There is a general consensus that C4 plants will have an average of $\delta^{13}\text{C}$ -12.5‰ -13‰ and C3 plants an average of $\delta^{13}\text{C}$ -26‰ -27‰. CAM plants can be on both ranges according to their contextual conditions (Barberena 2002) (see chapter VIII for local baseline). C4 maize can be identified in the New World because is almost the only C4 plant in the diet (Tykot 2004), although different values of $\delta^{13}\text{C}$ for maize can be found in the literature ($\delta^{13}\text{C}$ -9 to -16‰, -13.5 to -11.5‰ -12 to -14‰ or -10 to -14‰). Also, in some areas of the Americas, other C4/CAM plants might have played an important role in the human diet (e.g. Amaranthaceae, Cactaceae, Chenopodiaceae), enriching the $\delta^{13}\text{C}$ signals (Cadwallader *et al.* 2012). Therefore interpretations of the archaeological samples should be done ideally against a local and archaeological reference database. If the difference between values is smaller than 2.0‰, interpretations must be cautious as to the extent to which this might be

the result of a variation between samples coming from different environments and/or chronological moments (Calo & Cortes 2009). Also there is a multiplicity of factors that may induce variations in the isotopic signals of plants and animals (Calo & Cortes 2009), and their representation in human diet (Barberena 2002; Schwarcz 2006; Tykot *et al.* 2009).

Nitrogen isotope ratios for plants depend on how they get their nitrogen: whether by fixation or directly from the soil. The ratio also depends on water availability: dryer environments usually have higher $\delta^{15}\text{N}$ values (Bustamante *et al.* 2004). Deserts lacking a biological soil crust can produce plant values in excess of 12‰ (Coltrain *et al.* 2006). These values are passed through the food chain, enriching them by 3-4‰ on each trophic level. Human consumers of terrestrial plants and animals usually have a $\delta^{15}\text{N}$ in bone collagen of 6-10‰, whilst a diet based on marine or lacustrine resources has a $\delta^{15}\text{N}$ of 10-20‰ (Barberena 2002), although nitrogen values vary more than carbon according to local conditions. For instance, in arid and salty environments, there is enrichment in $\delta^{15}\text{N}$ values of terrestrial fauna without a correlative enrichment of the plants. This condition is likely to happen due to the climate and hydrological stress, which will lead to fixing of the $\delta^{15}\text{N}$ in the tissues (Barberena 2002). There is a strong negative correlation between annual precipitation and the amount of $\delta^{15}\text{N}$ in herbivores. High values ($> +10\text{‰}$) occur in areas with less than 400mm annual pp (Olivera & Yacobaccio 1999). Hence, in areas with less than 400mm rain per annum, “nitrogen isotope ratios cannot be used as marine or terrestrial indicators, but may provide some indication of the trophic level of the food consumed” (Sealy *et al.* 1987, 2707).

To reconstruct the isotopic diet, it is necessary to consider the difference between the substrate and the product (collagen or apatite). This difference is known as isotopic fractionation and generates an increment or diminishes the relative abundance on the isotopes of animal or plant tissues regarding their substrate (Barberena 2002). Different models have been applied in the analyses of ancient diet, though experimental data shows that the most widely accepted values for the human isotopic diet are $\delta^{13}\text{C}_{\text{col}}+5.1\text{‰}$ and values between $\delta^{13}\text{C}_{\text{ap}}+9.4\text{‰}$ or $\delta^{13}\text{C}_{\text{ap}}+12\text{‰}$ (Schwarcz 2006). $\delta^{13}\text{C}_{\text{col}}+5.1\text{‰}$ value is just valid for a mono-isotopic diet. For C3 protein and C4 non-protein diets, the offset between diet and bone collagen is 2.0–2.3‰. In C4 protein and C3 non-protein diets, the offset

increases to 9.6–10.2‰ (Tykot *et al.* 2009). However, I will use $\delta^{13}\text{C}_{\text{col}}+5.1\text{‰}$, since this is the most widely used model. Regarding apatite fractionation, this does not vary with respect to isotopic composition but to the class of animal (ranging from 8 to 14‰). For humans, it is not really clear which is the proper one, though there is a tendency to use +9.5‰ (Ambrose & Norr 1993; Tieszen & Fagre 1993); +12‰ (Harrison & Katzenberg 2003) or +13‰ (Prowse *et al.* 2004). Depending on the model used, a diet where protein and non-protein resources come from the same carbon source should have a difference of 4.4‰ (+9.5‰ model) or 7‰ (+12‰ model) (Tykot *et al.* 2009). If the difference is bigger, the protein fraction reflected in the collagen should be less than all diet and if the difference is smaller the protein fraction should be bigger (Barberena 2002). In this research, the $\delta^{13}\text{C}_{\text{col}}+5.1\text{‰}$, $\delta^{13}\text{C}_{\text{ap}}+9.4\text{‰}$ and $\delta^{13}\text{C}_{\text{ap}}+12\text{‰}$ models will be discussed.

Concerning the relevance of maize in pre-Columbian America, Tykot *et al.* (2009) conclude that our opportunity to estimate C4-maize in the human diet is poor because an apatite fractionation for humans is not experimentally possible and the scarce content of protein in maize (10%) means that it is underrepresented in bone collagen. The percentage of C4 in the diet will be achieved by stipulating the local C3 and C4 end-lines for plant resources.

Regarding oxygen and strontium isotopes, both have been used to infer climate change, diet and mobility patterns, among others.

Oxygen isotope values relate directly to local climate, temperature and humidity. Nearly all of the oxygen that goes into the formation of tooth and bone comes from the water we drink, which is ultimately derived from precipitation as rain and snow. The oxygen isotope ratio of the water you drink depends on the source of the water in precipitation, the distance from the coast, latitude and altitude and the local temperature of precipitation (Knudson 2009). For our purposes, we are interested in the ratio of heavy ($\delta^{18}\text{O}$) to light ($\delta^{16}\text{O}$) isotopes. The ratio of $\delta^{18}\text{O}$ and $\delta^{16}\text{O}$ (standard notation $\delta^{18}\text{O}$) varies throughout the environment, since water molecules that contain the lighter isotope of oxygen ($\delta^{16}\text{O}$) will evaporate more readily than water molecules that contain the heavier ($\delta^{18}\text{O}$) and this latter will condense and fall out in precipitation more readily than $\delta^{16}\text{O}$ (Knudson 2009). Therefore these differences in oxygen composition can be used to identify mobility in the past.

The strontium concentrations and isotope ratios in the soil, plants and bedrock vary according to local geology (Knudson *et al.* 2004). Their ratios ($^{87}\text{Sr}/^{86}\text{Sr}$) do not fractionate appreciably: therefore, the strontium isotope ratios measured in human enamel and bone reflect the strontium isotope ratios in the food and water consumed. When predominantly local strontium sources are consumed, these strontium isotope values in the human body reflect the biologically available strontium in the geologic region or regions in which an individual lived during enamel or bone formation (Bentley 2006). Residence in a geologically homogeneous region will mean that all components of the diet will have an identical strontium isotope ratio. In geologically heterogeneous regions, the diet will reflect a mixture of the strontium isotope ratios from local geological zones in proportion to the amount of food from each zone. Although there is substantial variation in the bioavailability of strontium in the environment, bone and tooth enamel, as slow-forming tissues, form over a long period of time and accumulate an average measure of bio-available strontium (Price *et al.* 2002; Price *et al.* 2004). Whilst adult bone regeneration is around 7–11 years, the actual rate of bone turnover varies from 2 to 20 years. Tooth enamel, on the other hand, forms during early childhood and will not re-crystallise or absorb elements from the environment after it has formed (Knudson *et al.* 2004).

Reference collection ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$):

The plant reference collection was built with those plants (native and domesticated) which are likely to have been eaten by grazing animals (camelids) and humans in the Loa and Salar de Atacama subarea (Table 29). These inferences were based on ethnobotanical, ethnographic and archaeological evidence. Previous plant and animal reference collections are also considered for analytical purposes (Ehleringer *et al.* 1992; Ehleringer *et al.* 1998; Evans & Ehleringer 1994; Kraus *et al.* 2001; Latorre *et al.* 2003; López 2010; Quade *et al.* 2007).

N	COLLECTOR	FAMILY	GENERA/SPECIE	AREA	masl
1	VMcRostie	Cactaceae	Echinopsis sp.	Vilama	3500
2	VMcRostie	Cactaceae	Opuntia camachoii	Tulan	3500
3	VMcRostie	Chenopodiaceae	Atriplex atacamensis	Tilocalar	2400
4	VMcRostie	Chenopodiaceae	Atriplex imbricate	Tulan	3500
5	VMcRostie	Chenopodiaceae	Chenopodium quinoa	Peine	?
6	VMcRostie	Cyperaceae	Scirpus sp.	Toconao	2400
7	VMcRostie	Fabaceae	Geoffroea decorticans	San Pedro	2400
8	VMcRostie	Fabaceae	Hoffmanseggia doelli	Tilocalar	2400
9	VMcRostie	Fabaceae	Phaseolus sp.	Peine	?
10	VMcRostie	Fabaceae	Prosopis sp. 2	San Pedro	2400
11	VMcRostie	Poaceae	Cortadera atacamensis	Tulan	2600
12	VMcRostie	Poaceae	Distichlis spicata	Tilocalar	2400
13	VMcRostie	Poaceae	Zea mays	Tulor	2200
14	VMcRostie	Portulacaceae	Cisthante salsoloides	Tulan	3500

Table 29. Plant specimens collected for the reference collection ($\delta^{13}\text{C}/\delta^{15}\text{N}$).

These samples were processed and analysed in collaboration with Dorinda Ostermann, manager of the Bloomsbury Isotope Environmental Facility of University College London. The protocol was based on Tykot (2004).

For animals, we count on the few local camelids from Tulan (Early Formative) measured by López (2010). These specimens are an isolated and small sample of the whole area and some of them do not have acceptable C/N ratios. Therefore more individuals should be tested to gain a better standard of these herbivores.

Archaeological samples for isotopes

Thirty-one archaeological individuals were sampled for different isotopes analyses. Twenty-nine correspond to human remains, of which twenty-one were sampled for $\delta^{13}\text{C}_{\text{col}}$, $\delta^{13}\text{C}_{\text{ap}}$ and $\delta^{15}\text{N}$ and the other eight were tooth sampled for $^{87}\text{Sr}/^{86}\text{Sr}$. The other two samples correspond to rodents as a reference signal for local $^{87}\text{Sr}/^{86}\text{Sr}$ (Table 30). The individuals analysed represent four sites from the Salar the Atacama (Calar, Toconao Oriente, Tulan 54, Tulan 58) and one from the Middle Loa river (Chorrillos), within a time span from the Early Formative to the Late Formative.

Site	Years	Sex	Age	Context	Bone	Apatite ($\delta^{13}C$)	Collagen ($\delta^{13}C$ -15N)	$\delta^{18}O$	87Sr/86Sr
Calar	200BC		Ind	3038	Jawbone	yes	yes	yes	
Calar	200BC		Ind	3485	Jawbone	yes	yes	yes	
Calar	200BC		Child	3050	Jawbone	yes	yes	yes	
Calar	200BC		Ind	3048	Skull	yes	yes	yes	
Chorrillos	820-770BC	M	25	D11 F2 E1 SW	Ribs?	yes	yes	yes	
Chorrillos	820-770BC	M	25	C14 F3 E1	Bone	yes	yes	yes	
Chorrillos	850-190BC	M	35-40	M9 F2 E1	Ribs	yes	yes	yes	
Chorrillos	850-190BC	F	Adult	M6 F3 E1	Ribs	yes	yes	yes	
Chorrillos	850-190BC	M	25-30	L9 F2 E1	Lower 3M				yes
Chorrillos	850-190BC	M	25-30	L9 F2 E1	Lower 3M				yes
Chorrillos	850-190BC	F	23-33	C14 F2 E1	Upper Right PM3				yes
Chorrillos	850-190BC	F	20-25	H 15 F1 E1	Lower R M1/2				yes
Chorrillos	850-190BC	?	Indeterminate	L12 F2 E1	Upper L M1				yes
Chorrillos	400-200BC	?	Indeterminate	C18 F1 E1	Lower RM2				yes
Chorrillos	850-190BC		Rodents	P17 F4SE	Teeth				yes
Chorrillos	850-190BC		Rodents	E12NW rasgo2	Teeth				yes
Toconao Oriente	310AD		Adult	4383	Jawbone	yes	yes	yes	
Toconao Oriente	10AD		Adult	4331	Skull	yes	yes	yes	
Toconao Oriente	230AD		Child	4263	Tooth + ground bone	yes	yes	yes	
Toconao Oriente	170BC		Adult	4340	Bone	yes	yes	yes	
Toconao Oriente	preiw.		Adult	4467	Jawbone	yes	yes	yes	
Tulan 54	1400-400BC	ind	Newborn	H9 body 17	Bone	yes	yes	yes	
Tulan 54	1400-400BC	ind	Newborn	I 5 body 8	Ribs	yes	yes	yes	
Tulan 54	1400-400BC	ind	Newborn	G3 body 25	Ribs	yes	yes	yes	
Tulan 54	1400-400BC	ind	Newborn	R2 I3 body 4	Ribs	yes	yes		
Tulan 58	400-180BC	ind	Child	C7 infant body	Ribs	yes	yes	yes	

<i>Tulan 58</i>	<i>400-180BC</i>	<i>F</i>	<i>50</i>	<i>Tomb 6</i>	<i>Ribs</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	
<i>Tulan 58</i>	<i>400-180BC</i>	<i>ind</i>	<i>Ind</i>	<i>Tomb 4</i>	<i>Bone</i>		<i>yes</i>		
<i>Tulan 58</i>	<i>400-180BC</i>	<i>ind</i>	<i>Ind.</i>	<i>Tomb 1 ent 1</i>	<i>Ribs</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	
<i>Tulan 58</i>	<i>400-180BC</i>	<i>?</i>	<i>Adult</i>	<i>C7</i>	<i>Teeth</i>				<i>Yes</i>
<i>Tulan 58</i>	<i>400-180BC</i>	<i>?</i>	<i>Adult</i>	<i>E1 tomb 1</i>	<i>Teeth</i>				<i>Yes</i>

Table 30. Archaeological individuals sampled for different isotopes.

Bone apatite: Bone apatite samples (Table 31) were prepared and analysed in collaboration with Dorinda Ostermann, manager of the Bloomsbury Isotope Environmental Facility of University College London. The protocol was based on Tykot (2004).

The samples were processed using procedures designed to remove non-biogenic carbon without altering the biogenic carbon isotope values (Koch *et al.* 1997, cited in Barberena 2002). Powder samples were obtained by grinding approximately 500 mg of powder, which was immersed in 2% sodium hypochlorite (NaOCl) to dissolve organic components (72 hrs). Non-biogenic carbonates were then removed in 1.0 M buffered acetic acid (CH₃COOH) for 24 hours. The integrity of apatite samples was assessed through yields obtained at each stage of the pre-treatment process. Samples were analysed at the Bloomsbury Environmental Isotope Facility (BEIF) at University College London on a ThermoFinnigan DeltaPLUS XP stable isotope mass spectrometer attached to a ThermoScientific Gas Bench II device. Standard and unknown sample material (normally >100µg) was loaded into glass vials, methanol rinsed and kept overnight in a 70°C oven. For analyses, each vial was manually acidified with 100% Phosphoric acid (0.1 ml) using a syringe injection via the screw cap septa. Precision for all internal (BDH, IAEA and IFC) and external standards (NBS19) greater than 1000mv is ±0.03 for δ¹³C and ±0.08 for δ¹⁸O. For all standards below 200-1000mv, the precision is ±0.04 for δ¹³C and ±0.13 for δ¹⁸O. All values are reported in the Vienna Pee Dee Belemnite notation (VPDB) relative to NBS19 (Gas Bench II 1999-2013).

SITE	YEARS	CONTEXT	ANALYSES	SEX	AGE	weight before	weight after	Bone part
Calar	200BC	3038	isotopes		ind	652.0mg	305.4mg	Jawbone
Calar	200BC	3485	isotopes		ind	516.0mg	81.9mg	Jawbone
Calar	200BC	3050	isotopes		child	488.2mg	50.4mg	Jawbone
Calar	200BC	3048	isotopes		ind	581.1mg	76.4mg	Skull
Chorrillos	820-770BC	D11 F2 E1 SW	isotopes	M	25	477.5mg	107.3mg	ribs?
Chorrillos	820-770BC	C14 F3 E1	isotopes	M	25	490.5mg	123.3mg	Bone
Chorrillos	850-190BC	M9 F2 E1	isotopes	M	35-40	445.6mg	16.4mg	Ribs
Chorrillos	850-190BC	M6 F3 E1	isotopes	F	adult	560.6mg	172.0mg	Ribs
Toconao Oriente	310AD	4383	isotopes		adult	589.3mg	24.3mg	Jawbone
Toconao Oriente	10AD	4331	isotopes		adult	635.6mg	22.7mg	Skull
Toconao Oriente	230AD	4263	isotopes		child	483.1mg	151.3mg	Bone
Toconao Oriente	170BC	4340	isotopes		adult	502.4mg	129.9mg	Bone
Toconao Oriente	pretiw.	4467	isotopes		adult	727.9mg	212.2mg	Jawbone
Tulan 54	1400-400BC	R2 I3 body 4	isotopes	ind	newborn	486.5mg	13.8mg	Ribs
Tulan 54	1400-400BC	H9 body 17	isotopes	ind	newborn	483.6mg		Bone
Tulan 54	1400-400BC	I 5 body 8	isotopes	ind	newborn	464.3mg	30.6mg	Ribs
Tulan 54	1400-400BC	G3 body 25	isotopes	ind	newborn	448.4mg	27.3mg	Ribs
Tulan 58	400-180BC	C7 infant body	isotopes	ind	child	466.6mg	140.3mg	Ribs
Tulan 58	400-180BC	Tomb 6	isotopes	F	50	543.2mg	223.6mg	Ribs
Tulan 58	400-180BC	Tomb 1 ent 1	isotopes	ind	ind.	460.8mg	142.0mg	Ribs

Table 31. Archaeological samples for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$.

Bone collagen: The samples (Table 32) were prepared and analysed in stable light isotope laboratories at Bradford University, UK. The following protocol is a copy of the one sent by this laboratory.

Stage 1: Sampling and Cleaning. Samples taken from the bone. Samples cleaned of surface contamination using powder abrasion equipment.

Stage 2: Demineralisation. Samples treated with 0.5M hydrochloric acid to dissolve mineral phase of bone. Kept in fridge at 4C until demineralised.

Stage 3: Heating and filtering. Samples heated in slightly acid deionised water (pH 3@ 70C), which allows collagen fibrils to go into solution. Samples then filtered with eze filters to remove larger non-collagenous matter.

Stage 4: Freezing and Freeze-drying. Remaining sample is collagen in suspension. Samples frozen ready for freeze-drying. This process removes water by sublimation.

Stage 5: Weighing and Preparation for Mass Spectrometry. Dried substance is pure collagen. This is weighed into tin capsules in preparation for mass spectrometry.

SITE	YEARS	CONTEXT	ANALYSES	SEX	AGE	Bone part	Weight
Calar	200BC	3038	isotopes		Ind	jawbone	8.955gm
Calar	200BC	3485	isotopes		Ind	jawbone	2.253gm
Calar	200BC	3050	isotopes		Child	jawbone	2.035gm
Calar	200BC	3048	isotopes		Ind	Skull	3.822gm
Chorrillos	820-770BC	D11 F2 E1 SW	isotopes	M	25	ribs?	3.104gm
Chorrillos	820-770BC	C14 F3 E1	isotopes	M	25	Ind	3.287gm
Chorrillos	850-190BC	M9 F2 E1	isotopes	M	35-40	Ribs	5.224gm
Chorrillos	850-190BC	M6 F3 E1	isotopes	F	Adult	Ribs	6.51gm
Toconao Oriente	310AD	4383	isotopes		Adult	jawbone	1.952gm + >500um
Toconao Oriente	10AD	4331	isotopes		Adult	Skull	3.038gm
Toconao Oriente	230AD	4263	isotopes		Child	Ind	1.132gm +tooth 2.849gm
Toconao Oriente	170BC	4340	isotopes		Adult	Ind	1.409gm
Toconao Oriente	preiw.	4467	isotopes		Adult	jawbone	3.932gm
Tulan 54	1400-400BC	R2 I3 body 4	isotopes	ind	Newborn	Ribs	0.287gm
Tulan 54	1400-400BC	H9 body 17	isotopes	ind	Newborn	Ind	0.674gm
Tulan 54	1400-400BC	I 5 body 8	isotopes	ind	Newborn	Ribs	1.131gm
Tulan 54	1400-400BC	G3 body 25	isotopes	ind	Newborn	Ribs	0.903gm
Tulan 58	400-180BC	C7 infant body	isotopes	ind	Child	Ribs	0.926gm
Tulan 58	400-180BC	Tomb 4	isotopes	ind	Ind	Ind	0.774gm
Tulan 58	400-180BC	Tomb 1 ent 1	isotopes	ind	ind.	Ribs	2.544gm

Table 32. Archaeological samples for $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{15}\text{N}$.

$^{87}\text{Sr}/^{86}\text{Sr}$ isotopes: Ten $^{87}\text{Sr}/^{86}\text{Sr}$ isotopes samples (Table 33) were processed and analysed in the context of a pilot study with the auspices and help of Dr. Jane Evans from the Natural Environment Research Council Isotopes Geosciences Laboratory, Nottingham UK.

The samples are six human teeth and two rodent bones from the Chorrillos site and two teeth from Tulan 58.

<i>N</i>	<i>SITE</i>	<i>AREA</i>	<i>PERIOD</i>	<i>YEARS</i>	<i>CONTEXT</i>	<i>SEX</i>	<i>AGE</i>
1	<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>L9 F2 E1</i>	<i>M</i>	<i>25-30</i>
2	<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>L9 F2 E1</i>	<i>M</i>	<i>25-30</i>
3	<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>C14 F2 E1</i>	<i>F</i>	<i>23-33</i>
4	<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>H 15 F1 E1</i>	<i>F</i>	<i>20-25</i>
5	<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>L12 F2 E1</i>	<i>?</i>	<i>Indeterminate</i>
6	<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>C18 F1 E1</i>	<i>?</i>	<i>Indeterminate</i>
7	<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>P17 F4SE</i>		<i>Rodents</i>
8	<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>E12NW rasgo2</i>		<i>Rodents</i>
9	<i>Tulan 58</i>	<i>Salar</i>	<i>Late Formative</i>	<i>400-180BC</i>	<i>C7</i>	<i>?</i>	<i>Adult</i>
10	<i>Tulan 58</i>	<i>Salar</i>	<i>Late Formative</i>	<i>400-180BC</i>	<i>E1 tomb 1</i>	<i>?</i>	<i>Adult</i>

Table 33. Archaeological samples for $^{87}\text{Sr}/^{86}\text{Sr}$ isotopes.

Summary

The methodology considers a multi-proxy approach which complements previous analysis of macro remains by focusing on the analysis of microfossils, sampling a large data set of tools associated with plant processing; as well as isotopes directed to understand the ingestion of plants and animals particularly the adoption of crops, especially maize, and movement or migration of individuals. All the samples were chosen according to the objectives, though they were conditioned by their availability, possibility of sampling and financial restrictions. Therefore the proportions sampled between sites and periods are not similar.

Regarding artefacts, some of the museum samples were not properly labelled; though if they came from sites and strata which represent the period and area studied, they were sampled anyway, even if the context was unclear. Hence, interpretation of the data needs to be done cautiously and being aware of the potential cultural processes that might have biased the archaeological context, especially in museum premises. For this reason, storage conditions and manipulation in the museums and during excavations were tracked as much as possible.

Also, natural processes that might affect the archaeological and systemic context are discussed. Taphonomical processes within soils are not clear and different perspectives have

been adopted regarding the preservation and origins of organic and inorganic remains in tools. Nevertheless, the review above suggests that microfossils adhering to plant processing tools can be used to identify some variables relating to plant use in the systemic contexts. These are the cultural value of the plant, the proximity of the plant to the site, their dispersion mechanisms as well as taphonomical evidence and its repetition through time and space (cultural patterns).

The reference collection of the main plants that grow in the area (Appendix 3) will hopefully allow discrimination between natural and cultural deposition, though in the future, new specimens as well as more precise identification at the specie level should be made. Within the multiple microfossil analyses, soil and other particles attached to the fissures of tools are not removed with the technique. The advantage is that the loss of any kind of microfossil is less probable, though the slides are not as clear as when traditional protocols are used for phytolith extraction. Archaeological microfossils will be identified and discussed using a conservative approach that considers as the main guideline the local reference collection. Presence/absence rather than statistics will be used to assess the distribution and meaning of different taxa through time and space. Therefore, considering the variables that might affect the microfossils recovered from the tools, the strength of this study relies on the systematic sampling of a large universe of tools for different sites and time periods and the comparative analysis of different data. Thus, general patterns rather than specific contexts will be outlined.

Regarding isotope analyses, these were limited by financial matters. Protocols are copied directly from each laboratory. I wanted to sample Tulan 54 for $^{87}\text{Sr}/^{86}\text{Sr}$, though enamel might be not enough. Not all the most representative sites have bone available for sampling and I was not possible to take sample from all sites.

CHAPTER VIII. RESULTS

Introduction

This chapter is divided into two subchapters: VII.1 Microfossils and VII.2. Isotopes. The microfossil subchapter is organised into two parts. In the first part, I will discuss the archaeobotanical aspects of the sample, such as the identification of archaeological microfossils and the problems and precautions to consider due to uncertainties, redundancy, contamination or post-depositional variables. In this regard, once I had identified the microfossils, I sorted out the ones that were most clearly a part of the systemic contexts and caused by cultural (rather than natural) variables. In the second part, I will discuss the “cultural” plant microfossils attached to tools and their variation through time and space. A preliminary identification of domestic (crops), wild and uncertain taxa this is used to evaluate their presence on artefacts at specific sites to evaluate the function of the tools and what resources they were used to process, and the potential significance of change in the presence of particular plants through time and space.

The isotope results are discussed with regard to the reference collection and archaeological samples. As the archaeological sample was small (thirty one individuals and twenty-one with integral data) and the reference sample does not cover the diversity of specimens (especially camelids), I present a general overview rather than a site-by-site approach.

VIII.1 Microfossils

a) Archaeobotany: Identification of microfossils

Microfossils were identified to different levels. Examples for each archaeological type and the different levels of identification are shown with pictures. Scale in picture represents 2.5um per unit (see Appendix 3 for reference collection). Phytoliths, starch grains, calcium oxalates and pollen were characterised to a morpho-anatomical and/or a taxonomical level when possible. Diatoms were used as humidity indicators, as the taxonomy of these algae is

still understudied in the Atacama area. Spherulites were classified as camelid/non-camelid coprolites.

Phytoliths were present on eighty-eight artefacts, starch grains on forty-three, diatoms on twenty-three, pollen on thirteen, spherulites on six, oxalates on three, whilst fifty-five artefacts did not have any microfossils (Figure 39).

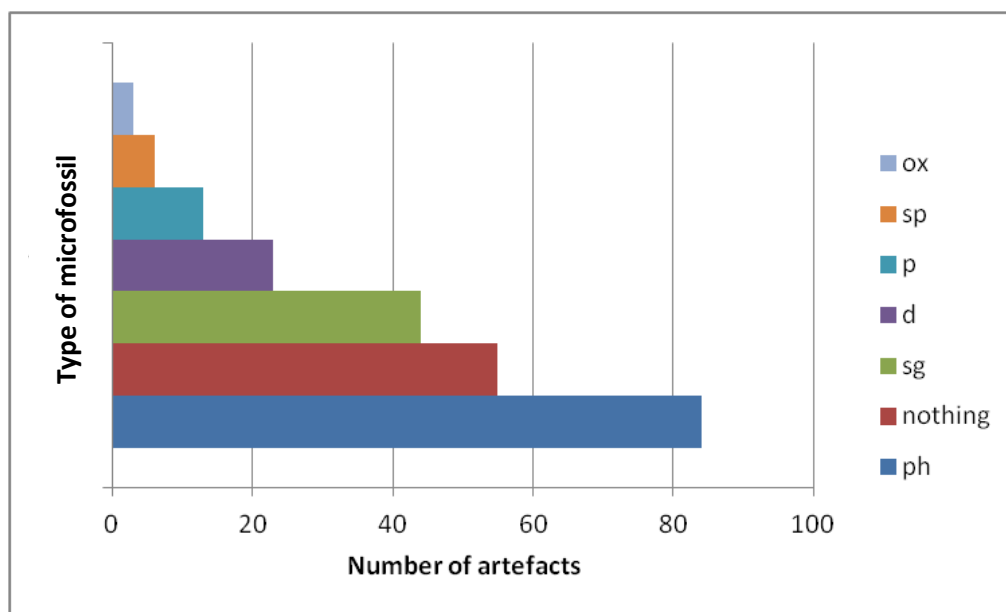


Figure 39. Types of microfossils on artefacts (ph: phytoliths, sg: starch grains, d: diatoms, p: pollen, sp: spherulites, ox: oxalates).

1. Phytoliths

Phytoliths were classified into different morpho-anatomical categories, which in some cases could be assigned to different taxonomical levels, though at the most precise level the identification could be compared to individual species (cf.) using local and non-local reference collections as main guidance. Other phytoliths could not be identified taxonomically due to their redundancy (e.g. spherical; hairs) and therefore they were characterised only at the morphological-anatomical level and stated as either monocot or dicot. Finally, some of the phytoliths could not be identified morphologically or anatomically due to their amorphous forms (NI). Here I present their distribution within the eighty-eight artefacts (Table 34).

ANATOMICAL/MORPHOLOGICAL		TAXONOMICAL LEVELS			PRESENCE	%
PHYTOLITH	PART OF THE PLANT	CLASS	FAMILY	GENUS/SP		
DICOT						
Honeycomb assemblage	Leaf	Dicot			3	1.46
Plateys	Various	Dicot			30	14.56
Polyhedrons	Leaf	Dicot			3	1.46
Sclereids	Various	Dicot			2	0.97
MONOCOT						
Bulliform	Leaf	Monocot			11	5.34
Cones	leaf/stem	Monocot	Cyperaceae		2	0.97
Cross	Various	Monocot	Poaceae		1	0.49
Granulate long cell	Stems	Monocot			5	2.43
Papillate long cell	Stems	Monocot			2	0.97
Rondels	Various	Monocot	Poaceae		12	5.83
Sinuate long cell	Stems	Monocot			9	4.37
Smooth long cell (cuadriculate)	Stems	Monocot	Various (reed)		2	0.97
Smooth long cell	Stems	Monocot			36	17.48
Smooth long cell (rods)	Stems	Monocot	Sedge		8	3.88
Trichome	Various	Monocot			4	1.94
MONOCOT/DICOT						
Hair cells	Various	Monocot/dicot			9	4.37
Spherical smooth	Various	Monocot/dicot			2	0.97
Sub-spherical	Various	Monocot/dicot			7	3.40
Regular spherical rugose	Various	Dicot	Cactaceae	cf. Opuntia sp.	3	1.46
Spherical rugose	Various	Dicot			7	3.40
Sub spherical with central perforation	Various	Dicot	Cactaceae	cf. Opuntia sp.	3	1.46
Trachieds	Various	Monocot/dicot			3	1.46
NOT IDENTIFIED						
NI	NI	NI			42	20.39
TOTAL					206	100.00

Table 34. Presence of different phytoliths on artefacts and identification level assigned (P: presence).

1.1. Monocots

1.1a Stems: Smooth, sinuate, granulate and papillate single/multi long cells (long psilate cells sensu Rosen pers comm. 2011) (25.2%)

Plant stems are variable in shape but tend to be elongated with smooth or sinuous, often interlocking borders (Pearsall 2000, 361) (Figure 40). Anatomically, they represent stems of monocot plants (Rosen 1992), though they do not possess any subfamily or tribal characteristics (Lu & Liu 2003). Pearsall (2000, 361) states that their usefulness in distinguishing among grass taxa varies depending on the family and associated epidermal projections.

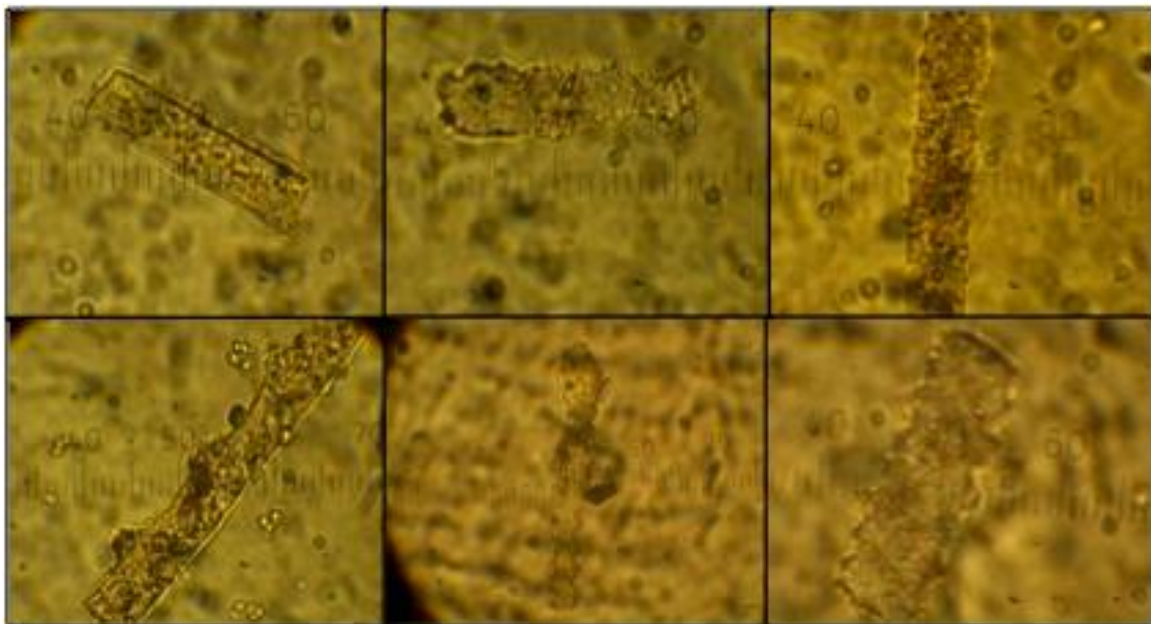


Figure 40. Long psilate cells with varied borders.

1.1b Rondels (lateral view) (5.8%) -Poaceae-

Most closely associated with the Pooideae, rondels are also found in the Arundinoideae, Panicoideae, and in the inflorescences of the Bambusoideae (Piperno & Pearsall 1998b). The most ubiquitous tribe in Atacama are the Pooideae, represented by species of the genus: *Bromus*, *Deyeuxia*, *Festuca*, *Nasella* and *Stipa*. Arundinoid and Panicoideae have less representation and a limited distribution, such as *Aristida* (Quade *et al.* 2007) and *Cortadera* sp. for the former, and *Pennisetum chilense* and *Zea mays* as a cultivated species for the

latter. This important crop only has rondels in the cob that have been defined as ruffle-top and wavy-top rondels, which are redundant with Poooid wild grasses (Fredlund & Tieszen 1994; Mulholland 1989; Mulholland 1993; Twiss *et al.* 1969). Logan (2006), using an assemblage-based approach and statistics for phytolith production in Andean highland grasses, was able to differentiate rondels which are relatively diagnostic for maize (ruffle-top rondel and narrow elongate rondel types). These types do not match the archaeological samples found (Figure 41), and the local maize of the reference collection did not produce rondels: therefore, it is not possible to discriminate whether some of the rondels recorded are positively maize.

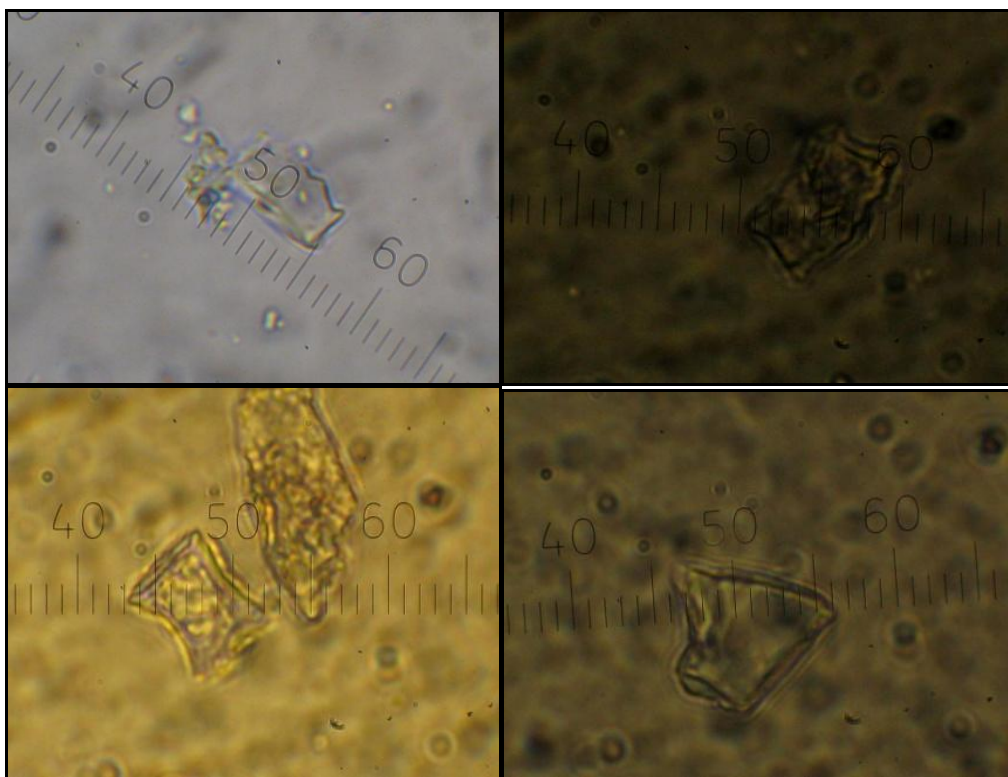


Figure 41. Rondels.

1.1c Cross or quadra-lobate (0.4%) -Poaceae-

Only one cross was found in the archaeological samples (Figure 42). The cross shape has been considered a panicoid marker (Pearsall 2000; Twiss *et al.* 1969), though it is also common in certain Bambusoideae and occurs in small numbers in the Chloridoideae, Arundinoideae and Pooideae (Piperno & Pearsall 1998b). Therefore in the area they could

be attributed to *Pennisetum chilense*, *Zea mays* or *Cortadera*, which showed crosses in the reference collection.

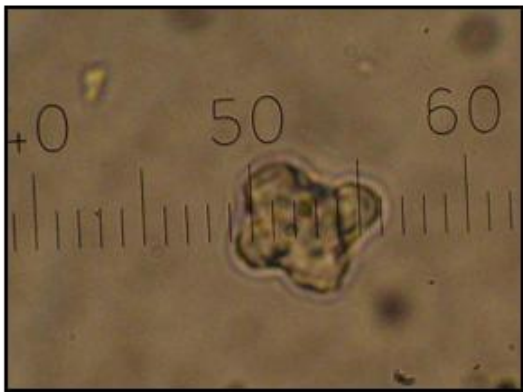


Figure 42. Cross shape.

1.1d Bulliform cells (5.3%)

These phytoliths are present in the leaves of some monocotyledons and rarerly can be assigned to any specific subfamily or tribal characteristics (Lu & Liu 2003), although in some cases general levels of identification can be inferred (Jenkins & Rosen 2007) (Rosen pers. comm. 2011) (Figure 43).

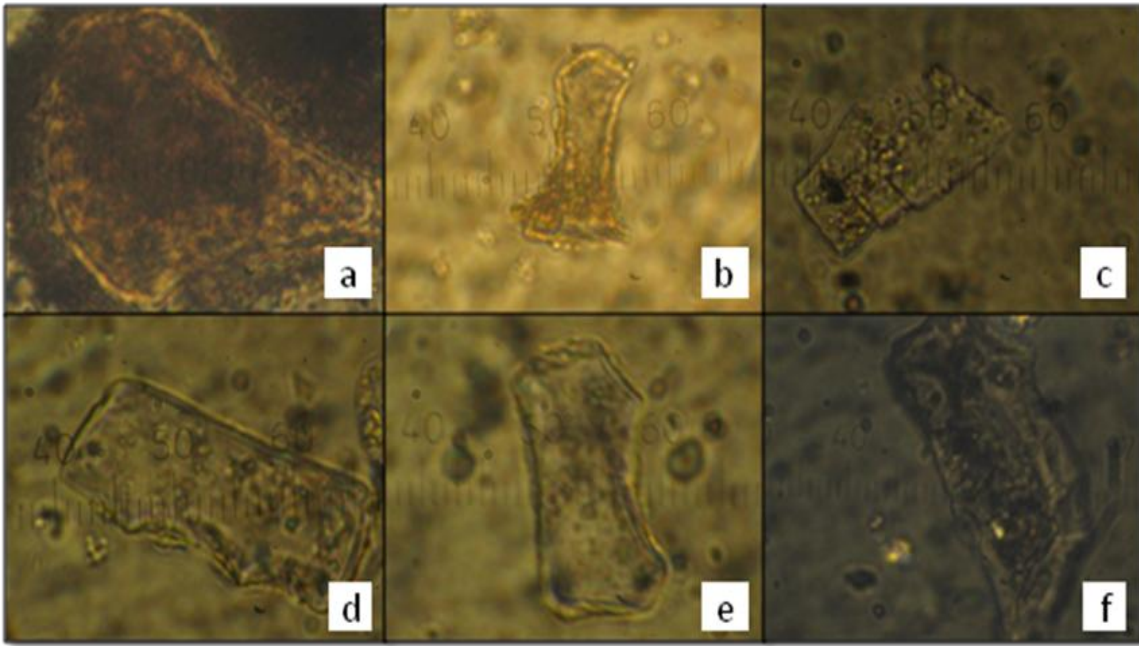


Figure 43. Bulliform cells including cf. *Phragmites* – b and reeds – c.

1.1e Sedge stems (3.8%)-Cyperaceae-

Ollendorf (1992) discusses the classification and terminology used for sedge phytoliths. Among the most common phytoliths found in leaves and stems are rod cells, hook bases, hair bases and cones (Ollendorf 1992). Elongated cells found in sedges overlap with the grass family and similar formations are also produced by ashy layers. In this sense, the difference between the rod cells and ash is that the formers should appear to expand and contract when magnification goes in and out of focus (Rosen pers. comm. 2012). Ashy layers were tested (although not from local geology) and they did not resemble the patterns found in my samples (g-h-i), hence I classified my samples preliminarily as sedge stems (Figure 44).

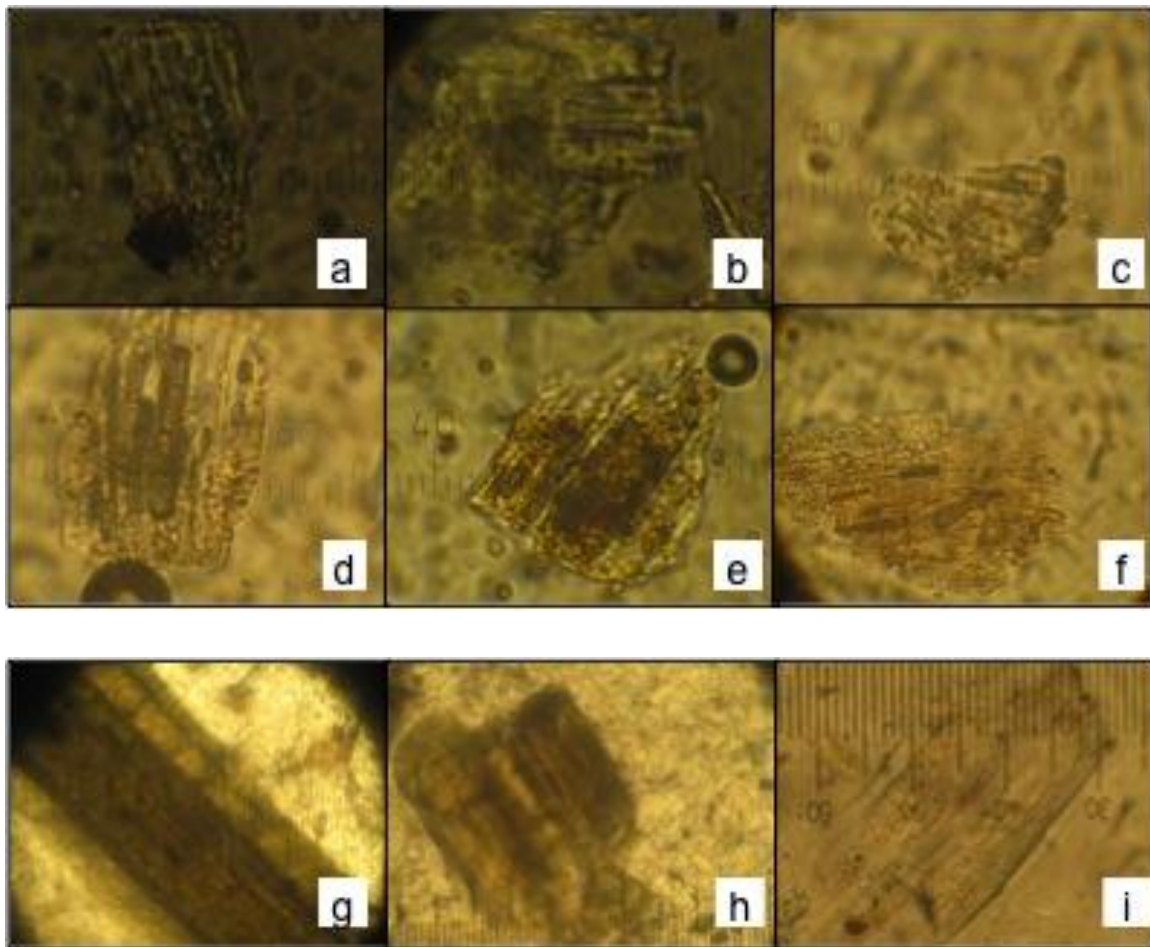


Figure 44. Rod cells cf. Cyperaceae (a-f) v/s ashes (g-i).

1.1f Cones (0.9%)-Cyperaceae-

Cones “seem to be the most consistent and characteristic phytoliths of sedges” (Ollendorf 1992, 92). These are present in leaves, culm and fruits (Fernández *et al.* 2009). They have pointed apices and smooth or nearly smooth surfaces (Piperno 2006c, 38) (Figure 45).

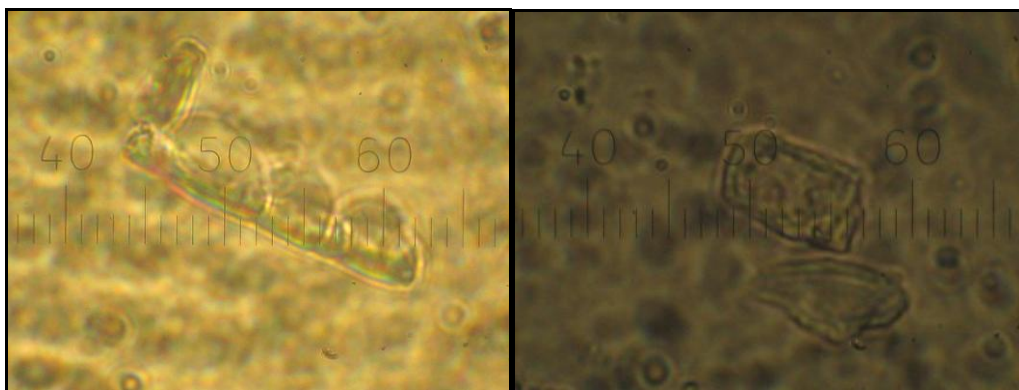


Figure 45. Cones cf. Cyperaceae.

1.1g Reeds long cells (0.9%)

These phytoliths were classified as reeds (Rosen pers. comm. 2012) (Figure 46). The second picture is similar to rod cells in the stems of *Scirpus californicus* of my reference collection.

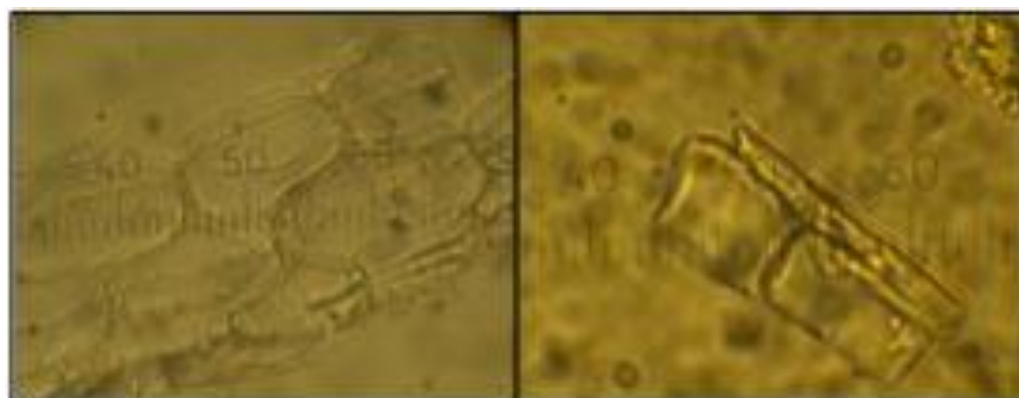


Figure 46. Long cells cf. Reeds.

1.1h Trichomes (1.9%)

Trichomes can be found in the leaves of a few monocot species of grasses and sedges where they do not have a diagnostic character (Tsartsidou *et al.* 2007). In the reference collection, these were recorded for Cyperaceae and Poaceae (Figure 47).

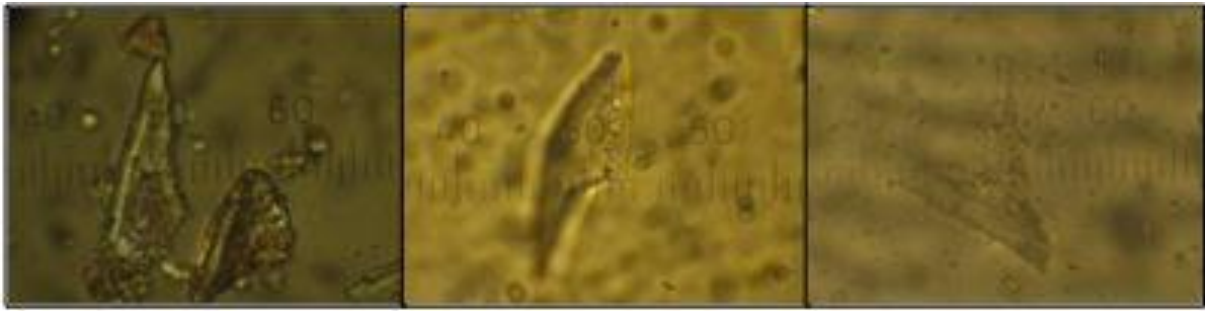


Figure 47. Trichomes.

1.2. Monocot/Dicot

1.2a Hairs (4.3%)

Piperno (2006c) refers to a major division between segmented and non-segmented hairs. These are primarily found in dicot, on which they can be useful in taxa discrimination (e.g. hair bases). In the reference collection of the area, hairs were registered for Asteraceae, Cyperaceae, Fabaceae, Poaceae and Verbenaceae; however, the archaeological hairs do not have a distinctive pattern that can be matched to any taxonomic level (Figure 48).



Figure 48. Hair cells.

1.2b Tracheid (1.4%)

Tracheids are present in vascular tissue and are characterised as cylindrical structures with spiral thickenings along the cell walls, sometimes composed of lignin (Figure 49). Generally, they do not play a role in plant identification (Piperno 2006c, 43) and are suitable to appear in monocot and dicot; although Tsartsidou *et al.* (2007) point out that they are characteristic of dicots. In the area, species from Asteraceae, Chenopodiaceae, Fabaceae, Poaceae and Juncaceae families showed this anatomical tissue.

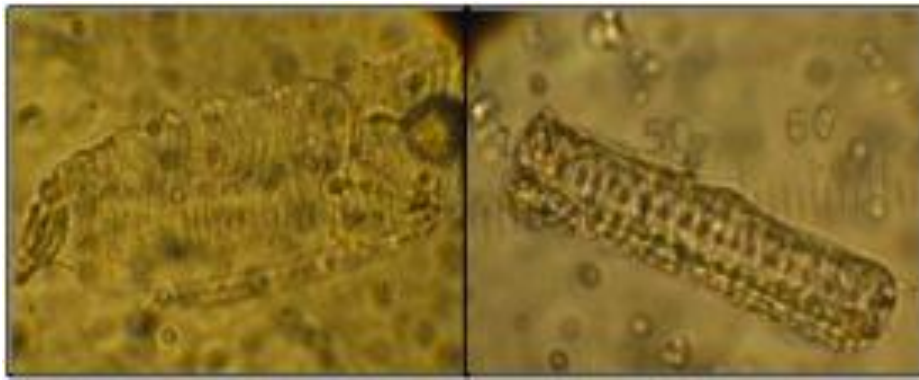


Figure 49. Tracheids.

1.2c Sphericals (10.6%) –Opuntia-

Dicots and monocots might present spherical to aspherical phytoliths that do not show any surface pattern (smooth) and they are not useful in taxa discrimination (Piperno 2006c, 38). Those from monocots usually range between 9-25um, whilst those in dicots are much smaller, at 3-9um (Piperno 2006c, 38). Some monocot families present nodulose and echinate decorations on the surface (e.g. Arecaceae) (Piperno 2006c; Piperno & Pearsall 1998b). Albert (1999) reports that some of the more consistent forms in woody dicots are spheroids and ellipsoids with surfaces that have scabrate or psilate textures. Iriarte & Paz (2009) report that the woody dicots produce spherical to aspherical phytoliths with surfaces that can be rugose, verrucose or nodular, although because these surfaces are difficult to distinguish, they have been encompassed as the globular granulate category under the ICPN code. One distinctive characteristic of woody dicot spheroids is that they range between 3-10um (Iriarte & Paz 2009).

In my local reference collection, *Baccharis scandens*, *Chenopodium quinoa*, *Opuntia* sp. and *Prosopis* sp. present spheroids in the leaf, seed, pad and pod respectively. In the archaeological samples, I assigned regular rugose spheroids ranging between 17.5 and 15um to cf. *Opuntia* sp. (Figure 50a) due to its correspondence with the reference collection. I also found “sub-spherical phytoliths with central perforations” (Figure 50b), very common in the fruit of *Opuntia* sp. (Korstanje & Babot 2007, 61). Other spheres with no diagnostic patterns could not be classified to a taxonomical level.

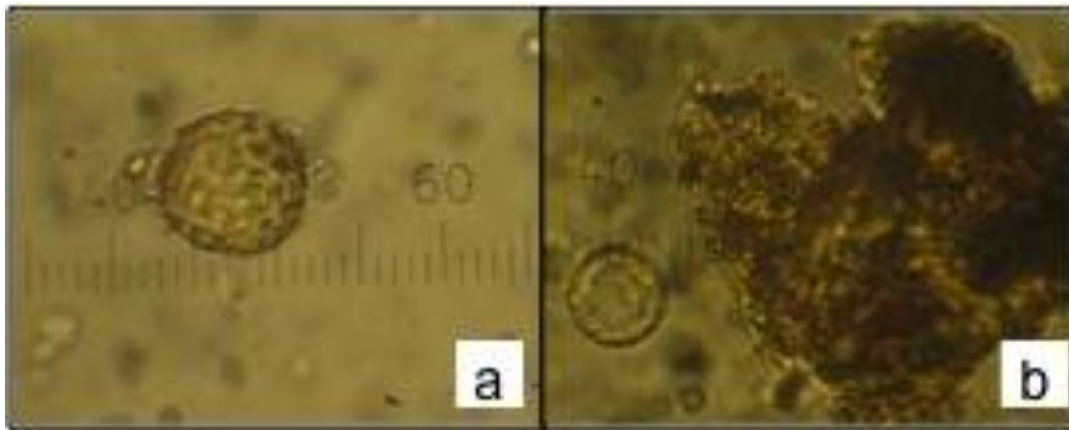


Figure 50. *Opuntia* sp. spherical phytoliths.

1.3. Dicots

1.3a Plateys, sclereids, jigsaw and honeycombs (18.6%)

I ascribe these phytoliths (Figure 51) to dicotyledonous plants (trees and herbaceous shrubs). Dicot phytolith forms are not identifiable to any taxonomic level, but they may be used in conjunction with other forms of analyses to identify the presence of vegetation composition. For instance, sclereids' phytolith morphology is often the same among unrelated taxa, though because they are almost entirely restricted to trees and shrubs, they are valuable indicators of woody vegetation (Piperno 2006c, 40). Polyhedral phytoliths, jigsaw puzzle pieces and honeycomb assemblages generally produced in the leaves of trees were found on my samples (Bozarth 1992, 194).

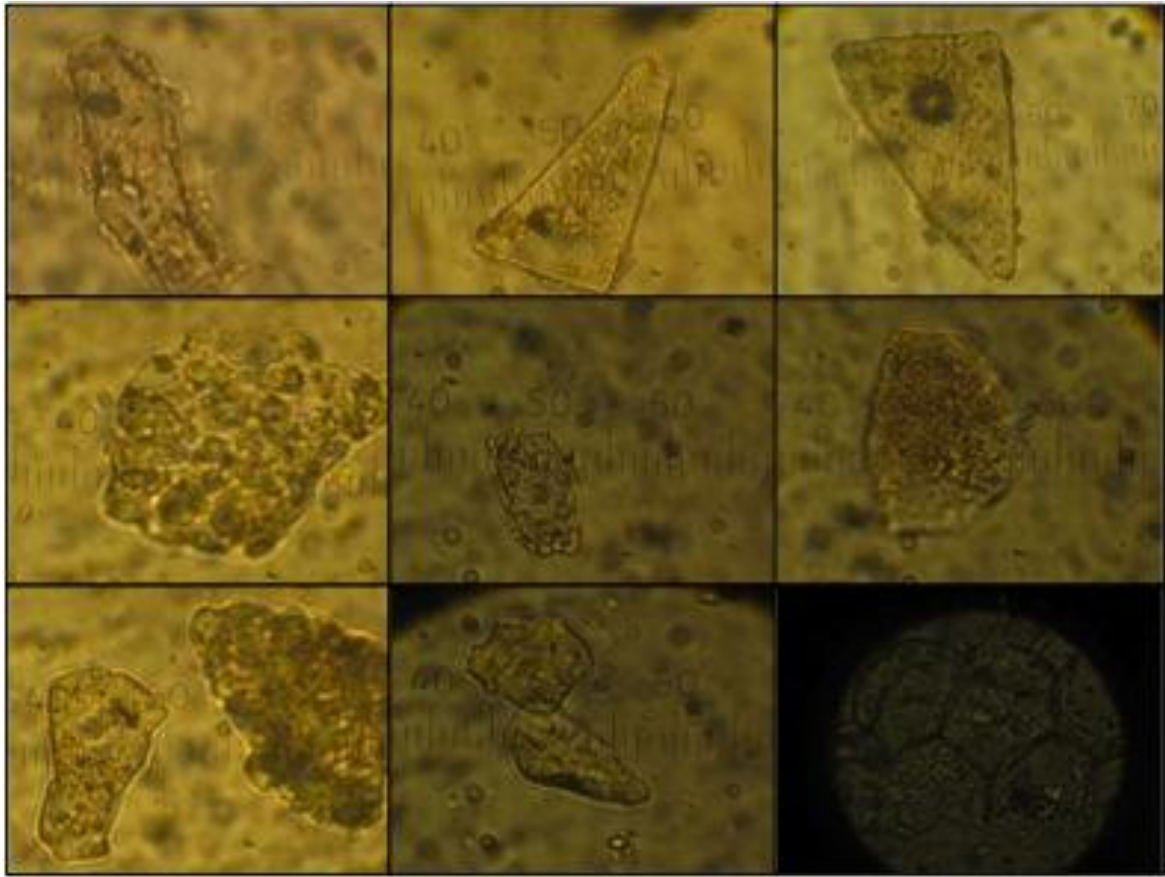


Figure 51. Dicotyledon phytoliths.

1.4. Not Identified (20.3%)

These types might be fragments of phytoliths and/or dicot phytoliths, which often produce irregular shapes that do not recur repeatedly (Rosen 2008, 1819) (Figure 52).

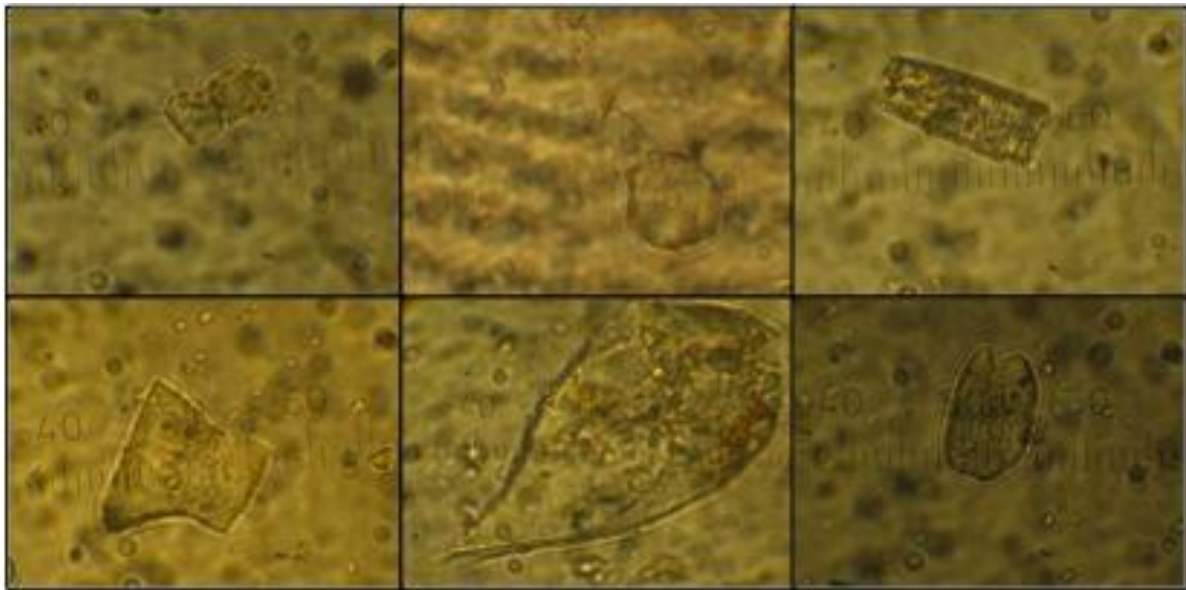


Figure 52. Non-identified phytoliths.

2. Starch grains

Starch grain identification was possible to a different extent. These were noted as cf. because their characteristics sometimes overlap between taxa, meaning that it is not possible to establish their taxonomical identification based on one or a few granules. On the other hand, some starches were ascribed to two possible taxa, as in the case of *Zea mays* and *Prosopis*, on which the archaeological starch grains shared most of the variants described for both species in the reference collection as well as in previous research. Other particles were characterised generically as tuber types. The reference collection of starches of the area was used as the main guidance, followed by Andean reference collections. All the starch grains identified come from edible parts (seeds, kernels, pods, tubers and fruits) of wild or cultivated plants which could be grown in the area or surroundings highlands. The following table (35) shows the level of identification achieved and the distribution within the forty-three artefacts that presented this microfossil.

<i>Id</i>	<i>Presence of taxa on artefacts</i>	<i>%</i>
<i>NI</i>	<i>17</i>	<i>26.15</i>
<i>cf. Prosopis</i>	<i>14</i>	<i>21.54</i>
<i>cf. Tuber type</i>	<i>8</i>	<i>12.31</i>
<i>cf. Cyperaceae</i>	<i>7</i>	<i>10.77</i>
<i>Cf. Chenopodiaceae</i>	<i>9</i>	<i>13.85</i>
<i>cf. Zea mays/cf. Prosopis sp.</i>	<i>4</i>	<i>6.15</i>
<i>cf. Hoffmanseggia sp.</i>	<i>2</i>	<i>3.08</i>
<i>cf. Cucurbitaceae</i>	<i>2</i>	<i>3.08</i>
<i>cf. Geoffroea decorticans</i>	<i>1</i>	<i>1.54</i>
<i>cf. Capsicum sp.</i>	<i>1</i>	<i>1.54</i>
<i>Grand Total</i>	<i>65</i>	<i>100.00</i>

Table 35. Starch grains presence and identification.

2.1. Not identified (26.15%)

Most of the starch grains could not be identified to any taxonomical level because of the taphonomical process or because their variance was not diagnostic (Figure 53). Further studies might clarify their taxonomy.



Figure 53. Non-identified starch grains.

2.2. Prosopis (21.54%)

2.2.a Cf. Prosopis sp. 1

Prosopis sp. 1 shows different pattern to *Prosopis* sp. 2. It is characterised by rounded forms, an invisible hilum, a centric cross in most cases, invisible lamellae, a simple structure and a mean of 3.0 and 3.1µm for length and width. Small grains similar to the ones reported in *Prosopis* sp. 1 were found in archaeological samples (Figure 54). In this case, because they match the local reference collection and similar starches were not present in other local plants, I classified them as *Prosopis* sp. 1, though small spherical grains can be highly redundant in plants (Korstanje & Babot 2007; Reichert 1913).

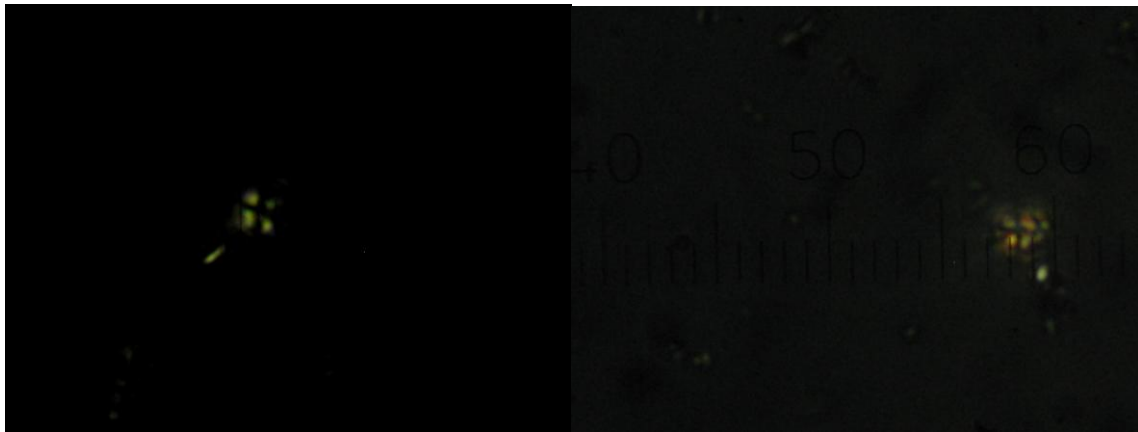


Figure 54. Cf. *Prosopis* sp. 1 starch grains.

2.2.b Cf. *Prosopis* sp. 2

Starch grains of cf. *Prosopis* sp. 2 were organised following Giovannetti *et al.*'s (2008) nomenclature:

A: Regular; rounded or faceted surfaces (5-6 facets). Grains are more or less symmetrical

A.1. Rounded surfaces

A.1.a. Spherical

A.1.b. Ovoid

A.2. Faceted surfaces

Despite some resemblance cf. *Zea mays* characterisation, their close similarity to the reference collection leads me to identify them as cf. *Prosopis* sp. 2 (Figure 55).

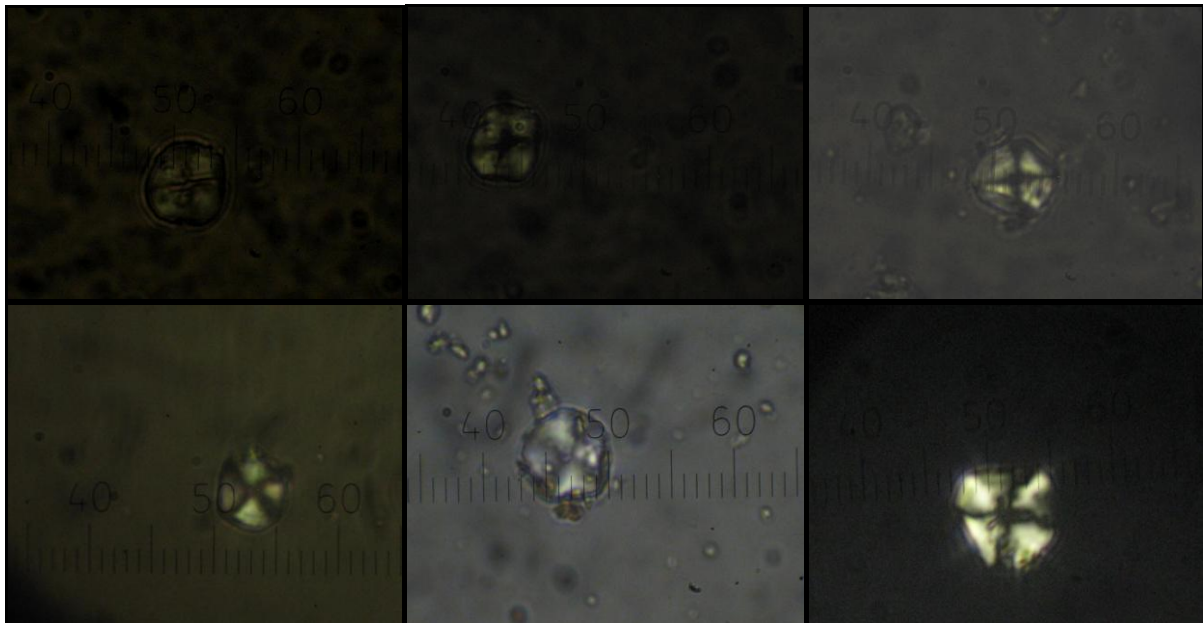


Figure 55. Cf. *Prosopis* sp. 2 regular starch grains.

B: Irregular, asymmetrical grains (Figure 56)

B.1. Partially irregular: with one or two protuberances and/or facets combined with rounded areas

B.2. Totally irregular: with more than two protuberances and/or facets irregularly disposed.

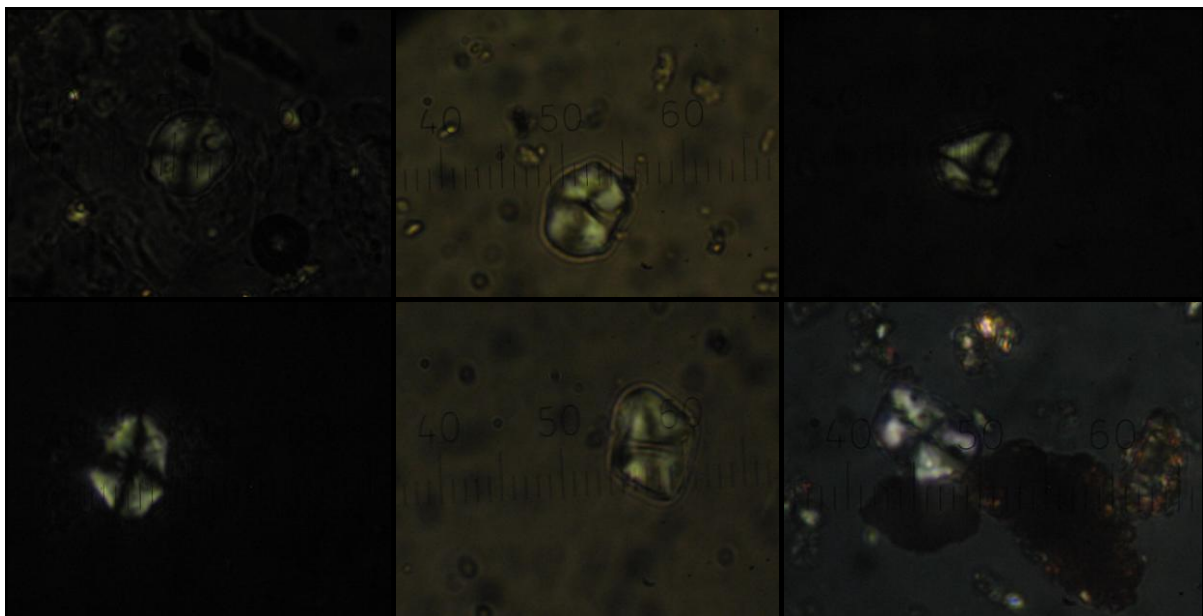


Figure 56. *Prosopis* sp. 2 irregular starch grains.

2.3. Cf. *Prosopis* or *Zea mays* (6.15%)

Considering my own reference collection and other descriptions for maize and *Prosopis*, it is hard to distinguish between the two taxa due to redundancy. Both species present angular/rough and circular/smooth forms and textures with sizes that can overlap between them (Figure 57). In Atacama, horny (angular and rough) and floury (circular and smooth) maize were used during the Formative period (Mangelsdorf & Pollard 1975). The two types of maize are known to differ in their starch grains' morphological characteristics and have been recognised by different archaeologists (Babot 2004; Cortella & Pochettino 1990; Cortella & Pochettino 1994; 1995; Dickau *et al.* 2007; Pearsall *et al.* 2003). I consider that their variants overlap with the regular types of *Prosopis* (Table 36).

Reference	Taxa	Forms	Size	Hilum	Fissure	Hilum position	Lamellae	Border
Others	Horny maize	Angular four or five-sided rough surface	10-30um	triangular/v shaped, dot/line	radiating	Centric	P/A	double line
	Floury maize	Spherical, irregular-elongated smooth surface	2-35um	triangular/v shaped, dot/line	radiating	Centric	P/A	double line
Own	Maize	Circular (50%) truncate (16%) and ovate (13%), although there are 10 forms more.	7.5-27.5um	circular (73%)	None (48.3%) linear (36.7%)	Centric (83%)	P (51%)	double line (100%)
Other	<i>Prosopis</i>	Irregular protuberance surface, circular smooth	6.71 to 27.44um (rounded smaller than irregular forms)	spherical and filamentous	linear, cross, y	Centric /eccentric	A	double/single line
Own	<i>Prosopis</i>	Rounded (30%), truncate (20%) predominate, though there is a high diversity of forms such as trasovate, hexagonal, pentagonal etc (50%).	7.5-22.5um	circular (95%)	linear (16%)	Centric (97%)	P (66%)	single line (80%) double (20%)

Table 36. *Zea mays* versus *Prosopis* starch grains in my own and others' reference collections (See Appendix 3 and 4) (P: Present/ A: Absent).

The discrimination of maize and *Prosopis* by using the birefringence power (Giovannetti *et al.* 2008) is not consistent with my own samples; moreover, birefringence is susceptible to taphonomical changes in archaeological grains. The same happens with the fissure, which for maize is often described as “radiating”, though taphonomical processes (freezing, toasting, grinding) may affect this pattern (Babot 2007). However, I did not find this variant in my maize sample. Lema *et al.* (2012) confirm these observations, considering that

spherical grains can be either maize or *Prosopis* and their hilums are difficult to assess as star-fisurate of maize or star fusiform of *Prosopis*. In their work, they classify faceted hexagonal forms with star fisurate as maize and the more irregular forms as *Prosopis*; though in my reference collection *Prosopis* shows hexagonal grains as well. Other variants could be borders that have been described as double in maize and single in *Prosopis*, but this character also overlaps in my reference collection and the lack of lamellae in *Prosopis* is not consistent in all of the cases of my reference collection. Alternative microfossils in the samples have not given further clues to resolve this taxonomical difficulty; hence I will refer to them as *Zea/Prosopis* until further analyses can clear this uncertainty.

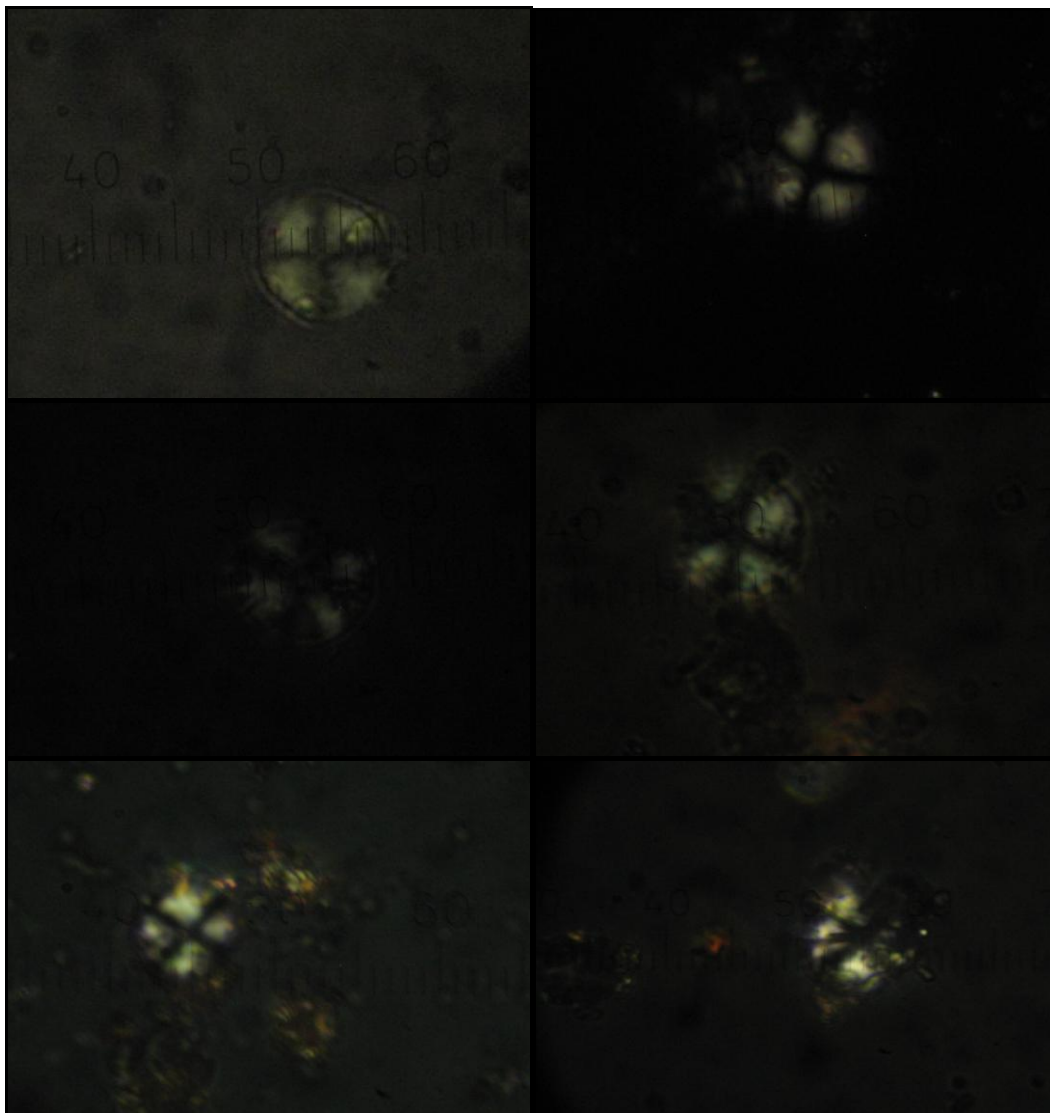


Figure 57. Cf. *Zea/Prosopis* starch grains.

2.4. Cf. *Geoffroea decorticans* (1.54%)

The archaeological grain identified as *Geoffroea decorticans* (Figure 58) shows a slightly truncated form which might be a compound grain due to the pattern of the extinction cross. This form with the structure as well as the size range allows me to identify it as *Geoffroea*, which has 50% of the grains with compound structure, although the range of size is slightly smaller in this case.

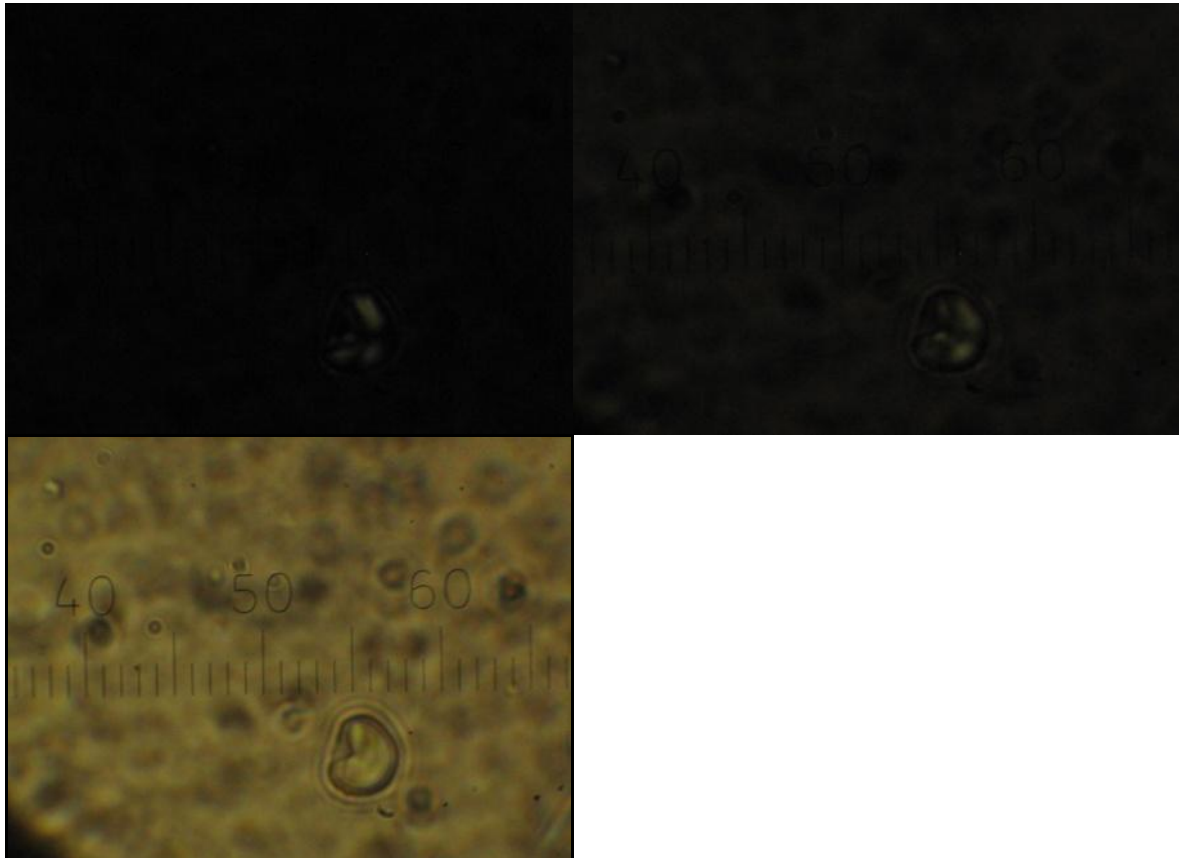


Figure 58. Cf. *Geoffroea decorticans* starch grain.

2.5. Cf. *Tuber* type (12.31%)

Bells and oval shaped grains have been identified as tuber types. Piperno *et al.* (2000, 897) indicate that bell-shaped grains are primarily confined to subterranean organs of plants, though Cucurbitaceae may also produce them: therefore, their presence in the archaeological sediments must be evaluated according to the whole microfossil assemblage for taxa assignment (Korstanje & Babot 2007, 45). In Atacama Cucurbitaceae, more precisely *Lagenaria* sp. is the earliest and more ubiquitous crop found in the area during the

Formative; though I did not find starches in the *Lagenaria* rind sampled and neither had I found spherical phytoliths common to this family. Starch grain studies of roots and tubers are rarely present, in small quantities, or absent entirely (Zarillo 2005, cited in Logan 2006) and neither Andean tubers reference collection (Cortella & Pochettino 1995; Logan 2006) nor my local reference collection gave a similar bell type to that found in the archaeological samples. Several wild tubers and/or rhizomes are recognised for the area with different taxonomical levels of identification (see CH.V). Munizaga *et al.* (1958) refer to wild tubers as an important source of food. The same authors refer to thirteen types of domestic potato in the area. Therefore, I still have to look for domestic or wild tubers that could be responsible for these starches (Figure 59).

Also oval forms with eccentric hilum and visible lamellae are likely to be tubers (Babot 2004; Korstanje & Babot 2007; Logan 2006). One of them, lacking lamellae and with an obscured extinction cross (59a), might represent the freeze-dried taphonomical process common in the Andes for tuber storage (Babot 2003; Babot 2004).

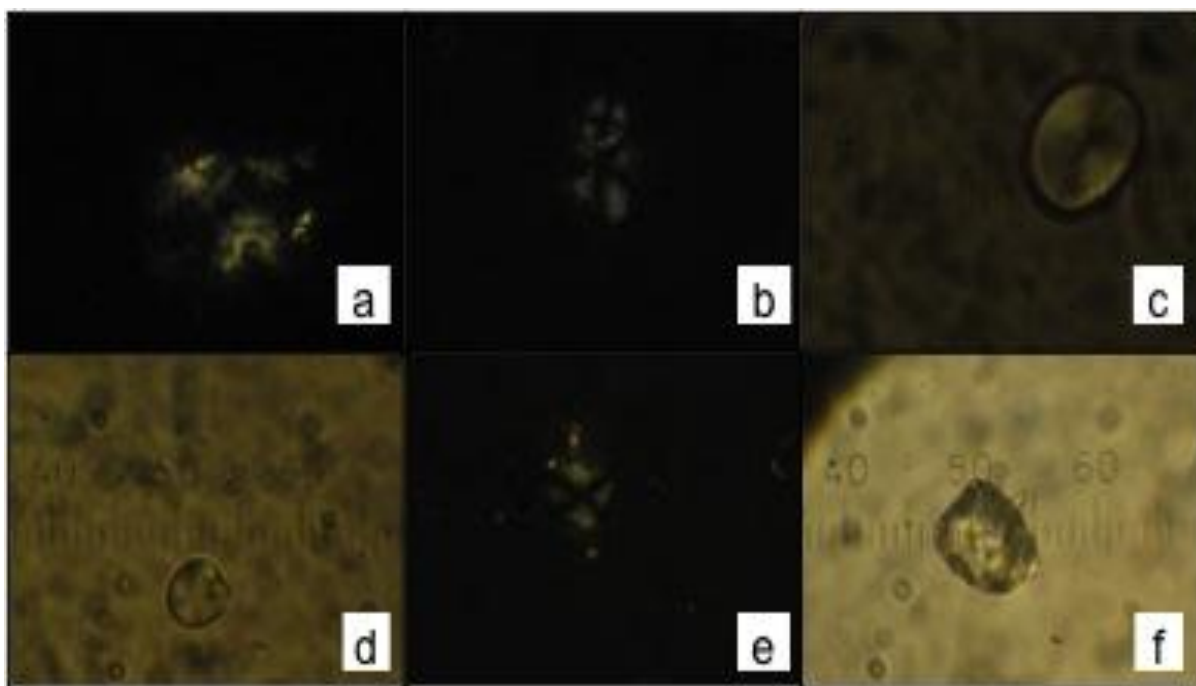


Figure 59. Cf. Tuber-type starch grains.

2.5.1 Cf. Hoffmannseggia sp. (3.08%)

Within tuber types, some starches present more affinity with the variants of *Hoffmannseggia* sp. of the reference collection, and therefore were ascribed provisionally to this species (Figure 60). These present a size greater than 15µm when they have a simple and irregular truncate form and the presence of a cavity. The compound grain shows the same morphology as in the reference collection, although slightly smaller.

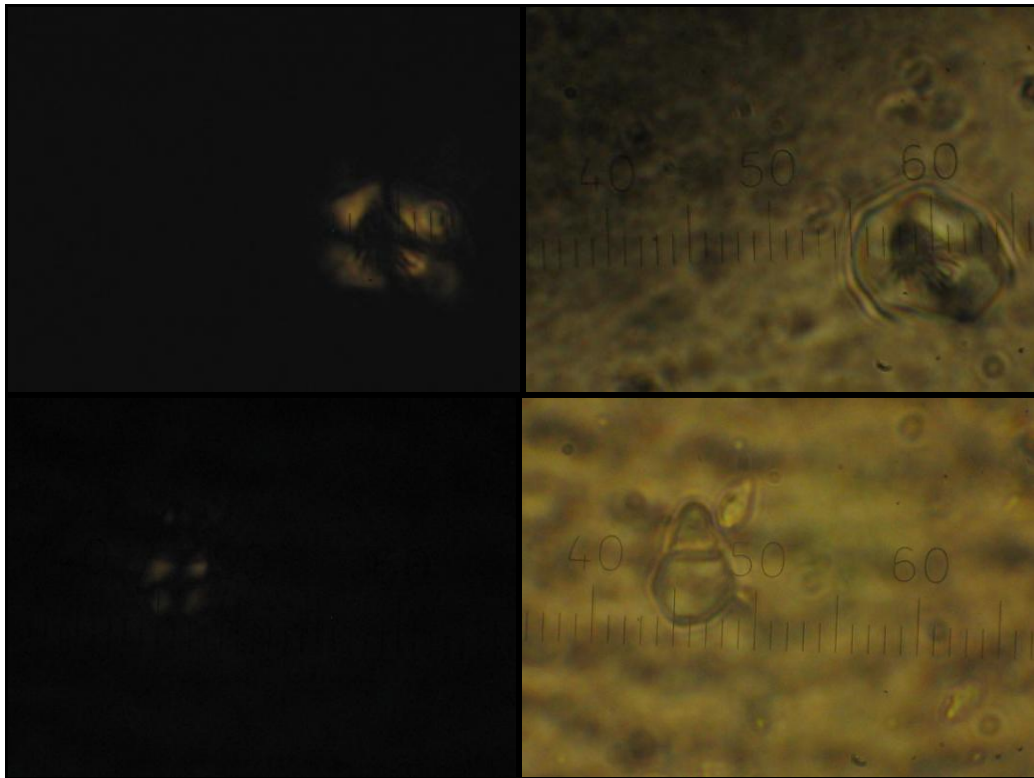


Figure 60. Cf. *Hoffmannseggia* sp. starch grains.

2.6. Cucurbita sp. (3.08%)

Starch grains were ascribed to this genus (redundant between species) following Babot (2004) as round, ranging between 8.5um-25um, with a clear hilum as a dot or as a rounded cavity, no visible lamellae and a clear extinction cross. The second resembles Duncan *et al.*'s (2009) descriptions for Cucurbitaceae *Lagenaria siceraria* flattened hemispherical type (Figure 61). However, most of the characteristics described by Duncan were not evident in this starch and therefore this identification needs further comparison.

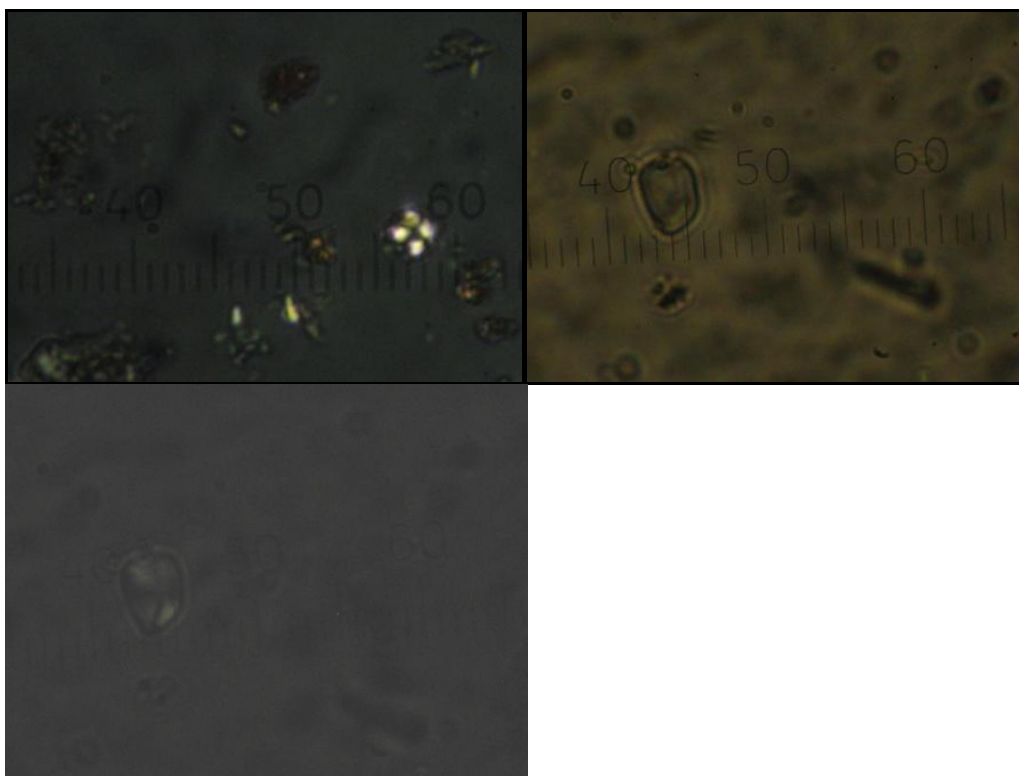


Figure 61. Cf. Cucurbitaceae starch grains.

2.7. Cf. Capsicum sp. (1.54%)

Babot (2004) and Korstanje and Babot (2007) defined single grains of variable morphology, commonly oval but also kidney-shaped, spherical, ellipsoidal, triangulate and polyhedral with rounded sides. The length is around 10-23um, with hilum in a point, lamellae not visible, extinction cross visible and centric (Babot 2004, 101). The grain identified as *Capsicum* (Figure 62) is very similar to some of their types described as polyhedral with rounded sides, with four visible arms intersecting at a point and measuring 20um. Though Perry *et al.* (2007, 986) have defined that “All five species of domesticated chili peppers produce large, flattened lenticular starch grains with a shallow central depression, not unlike a red blood cell in appearance...”. Hence more reference collections, especially from each studied locality, should be performed and this archaeological specimen should be further contrasted.

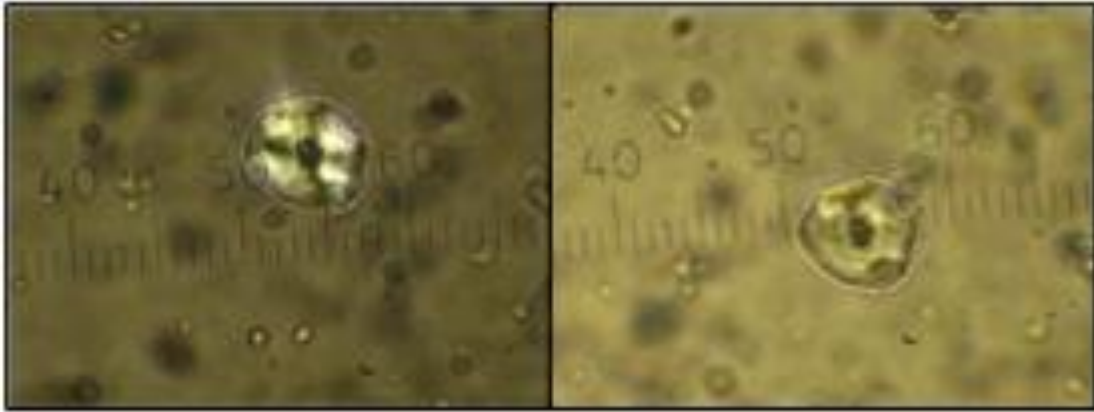


Figure 62. Cf *Capsicum* starch grain.

2.8. Cyperaceae (10.77%)

Starch grains were ascribed to this genus when they showed a round/square cavity in the central area which has taxonomical value *sensu* the local reference collection and previous characterizations (Messner 2008). They have oval and circular shapes, invisible and centric hilum, invisible lamellae and size within a range of 25um to 2,5um (Figure 63).

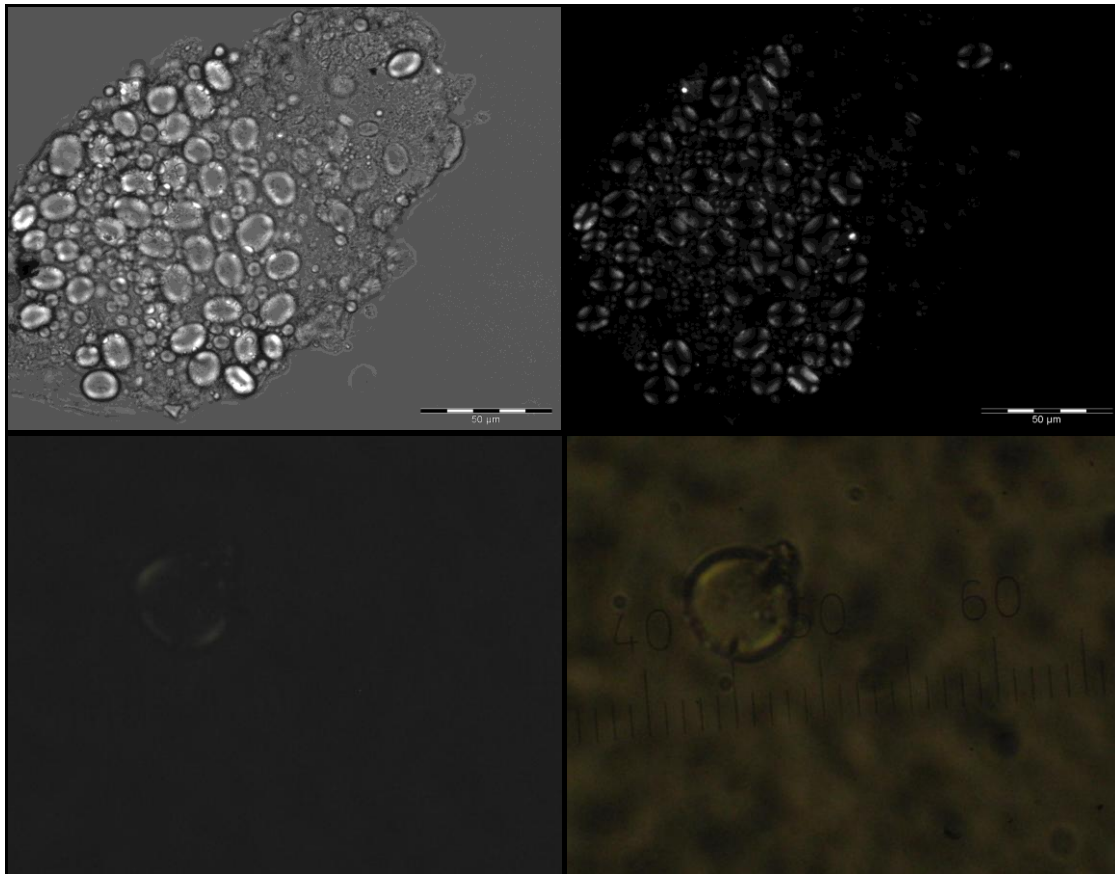


Figure 63. Cf. Cyperaceae starch grains.

2.9 Cf. *Chenopodiaceae* (13.85%)

This category was used in the first instance following the definition of cellular structures composed by numerous small granules cemented by amorphous starch present in Andean pseudocereals (Babot 2004). But in this case, the samples are not so clear as to assign them to *Chenopodiaceae* or other mineral formations (Figure 64).



Figure 64. Ambiguous agglomerates.

3. Calcium oxalate

Even if Hather (2000) argues that calcium oxalate crystals are of no diagnostic value, the scarce oxalates found are preliminary recognised as cf. *Chenopodium sp.* (Figure 65a), and *Prosopis* (Figure 65b-c) *sensu* the local reference collection and previous characterizations (Korstanje & Babot 2007).

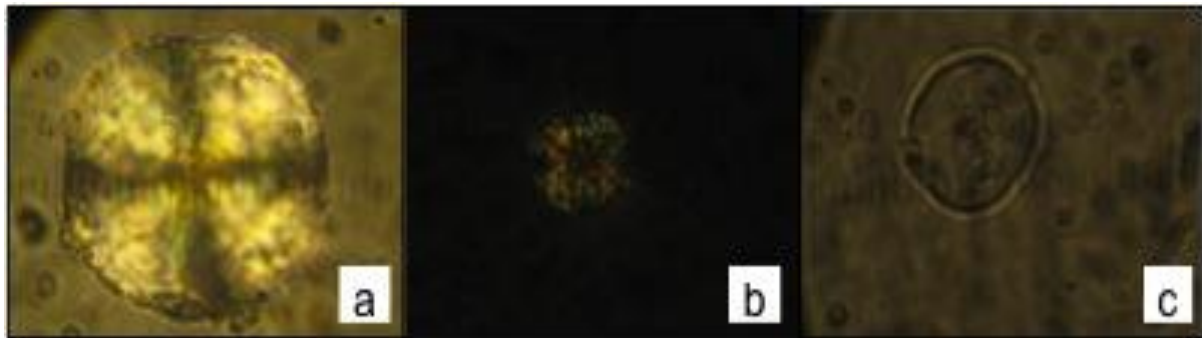


Figure 65. Calcium oxalates.

4. Diatoms

Due to the lack of studies of diatoms from the area, these are used as humidity indicators, though some genera such as *Denticula*, *Achnanthes*, *Nitzchia* and *Surillella* have been recognised (Figure 66).

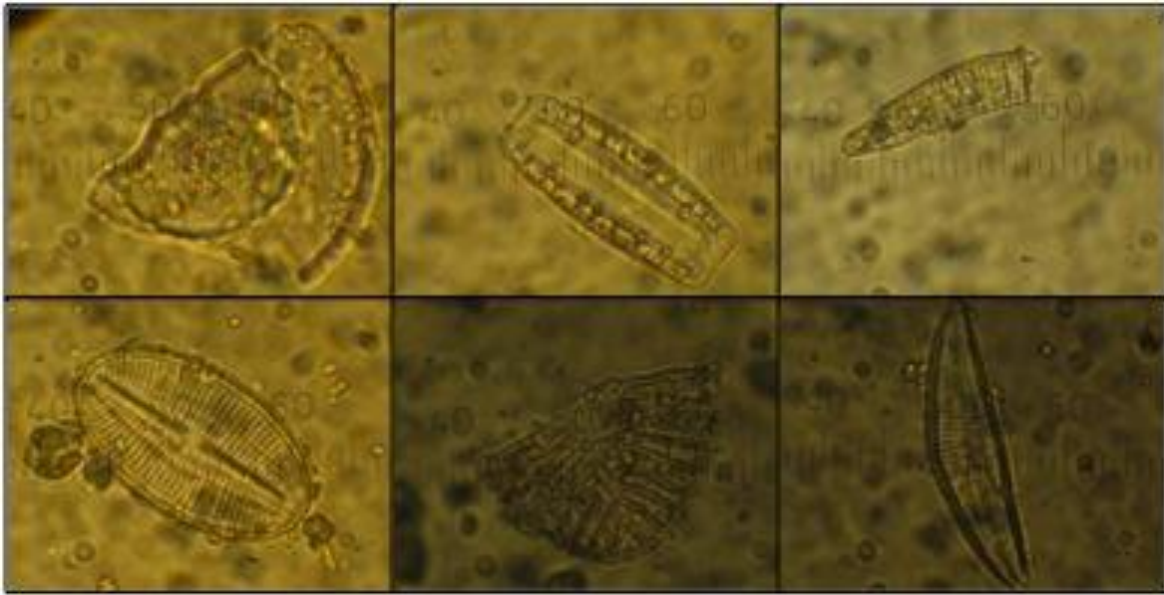


Figure 66. Diatoms.

5. Pollen

Most of the pollen found is ascribable to Poaceae (65%). The identification of these microfossils was not done with a 100x scope and immersion oil and therefore they were characterized just to a general level (Figure 67).

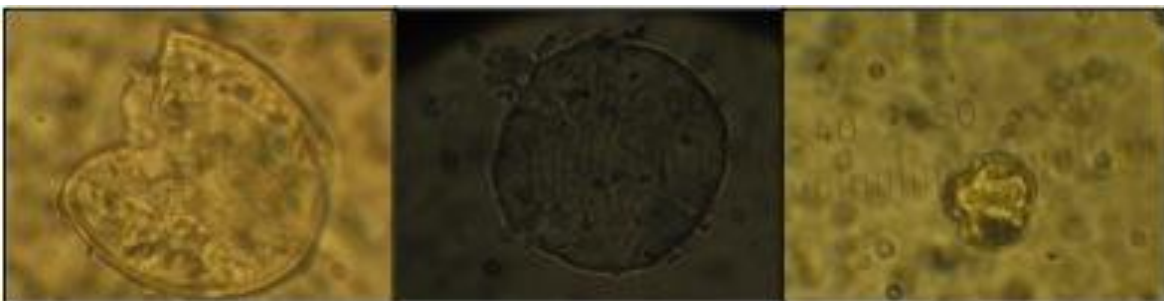


Figure 67. Pollen.

6. Spherulites

All the spherulites were rounded type, ranging between 3.5um-5um, and were attributed to camelids (Korstanje 2001b; 2005) (Figure 68).



Figure 68. Camelid spherulites.

b) Taphonomy

In order to interpret the results of the microfossil analysis it is necessary to distinguish between microfossils that originate from the systemic/cultural context, as opposed to any 'contamination' that may originate from natural processes taking place since the original occupation of the sites. This requires a consideration of the formation process that might have influenced the attachment of microfossils to the tools.

1. Phytoliths

Most of the phytoliths come from stems, leaves and inflorescence of monocot plants as well as dicot leaves and wood. These general levels of identification do not allow us to establish cultural manipulation and because these plants actually grow in all of the sites (and considering paleo-environmental information, they probably grew in all of the sites when these sites were occupied), these microfossils could be a result of natural processes either during the 'systemic' activities of the original occupants or the natural process of bioturbation that can affect the archaeological context. In the desert, wind and *in situ* plant decay could be the most recurrent cause for phytolith deposition. Even if their presence within the sites could reveal human activities, their general levels of identification do not allow me to gain further interpretation by including them in the discussion. These phytoliths are present in almost all of the sites (Figure 69).

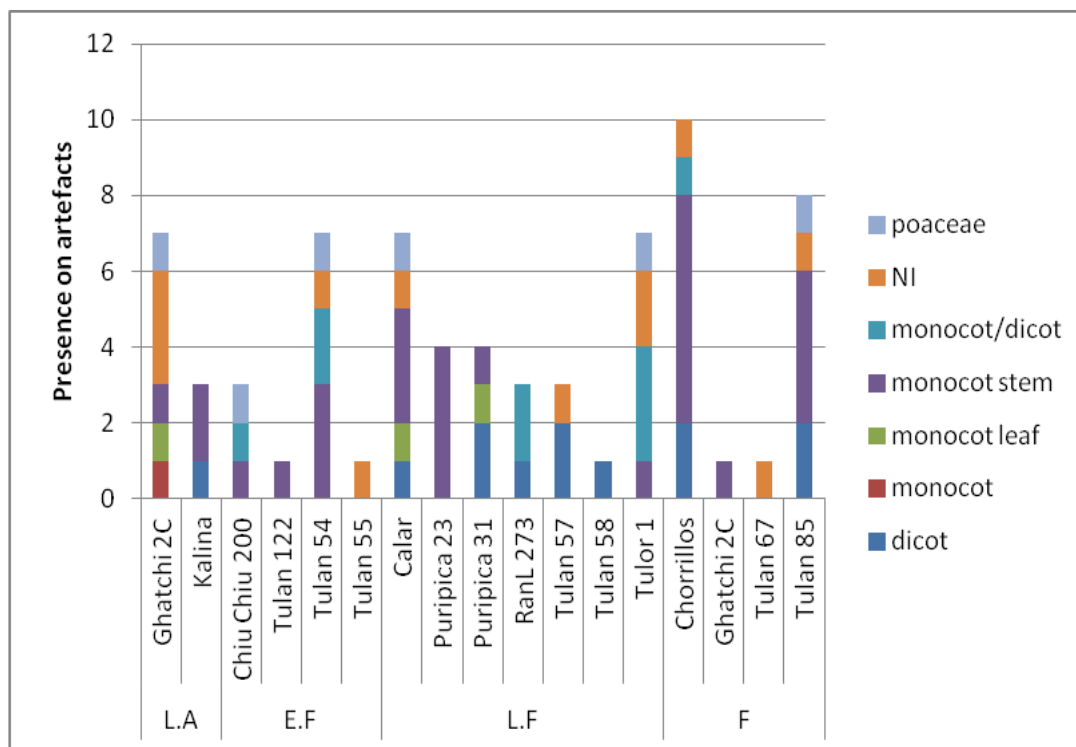


Figure 69. Artefacts with presence of phytoliths considered most likely to be the product of natural formation process (LA: Late Archaic, E.F: Early Formative; L.F: Late Formative; F: Formative -represents all the Formative sub-periods-).

Nevertheless *Opuntia* sp., Cyperaceae and reeds (*Scirpus* cones and sedge/reed stems phytoliths) could be reflecting cultural manipulation in the systemic context because they are edible plants and their attachment to the tools is unlikely to have happened naturally. Cyperaceae and reeds grow only in water streams, whilst the sites are in most cases located in the arid slopes or at some distance from the greener patches. Their presence in ten sites on either grinding tool or hoes (Figure 70) suggests that their rhizomes and stems were cut and/or dug and then ground. Cyperaceae phytoliths on mortars represent stems rather than the starchy tubers. However, mature tubers could have phytoliths, as they have already developed the tough periderm and cortex which might have some phytoliths. Therefore I assume that Cyperaceae was processed for food in these cases. Also it could be that starch grains did not survive but phytoliths did, as these artefacts come mainly from the surface of the sites (Ghatchi 2C, Kalina, Tulan 85). However, in other sites, artefacts from the surface also had starch grains, so at this point I cannot generalize explanations for this pattern. In this sense, taphonomic studies have not given conclusive answers (see CH.VII, taphonomy).

Dry fruits of *Opuntia* could be deposited in the sites by wind and then become attached to the artefacts within the matrix, though their presence in six different sites (Figure 70) whose local vegetation varies in distribution (oases, ravines) and their presence mainly on hoes (83%) allow us to propose that these microfossils could have been attached by some kind of manipulation either to extract the fruit from the plants or to cut/process them once in the habitation area.

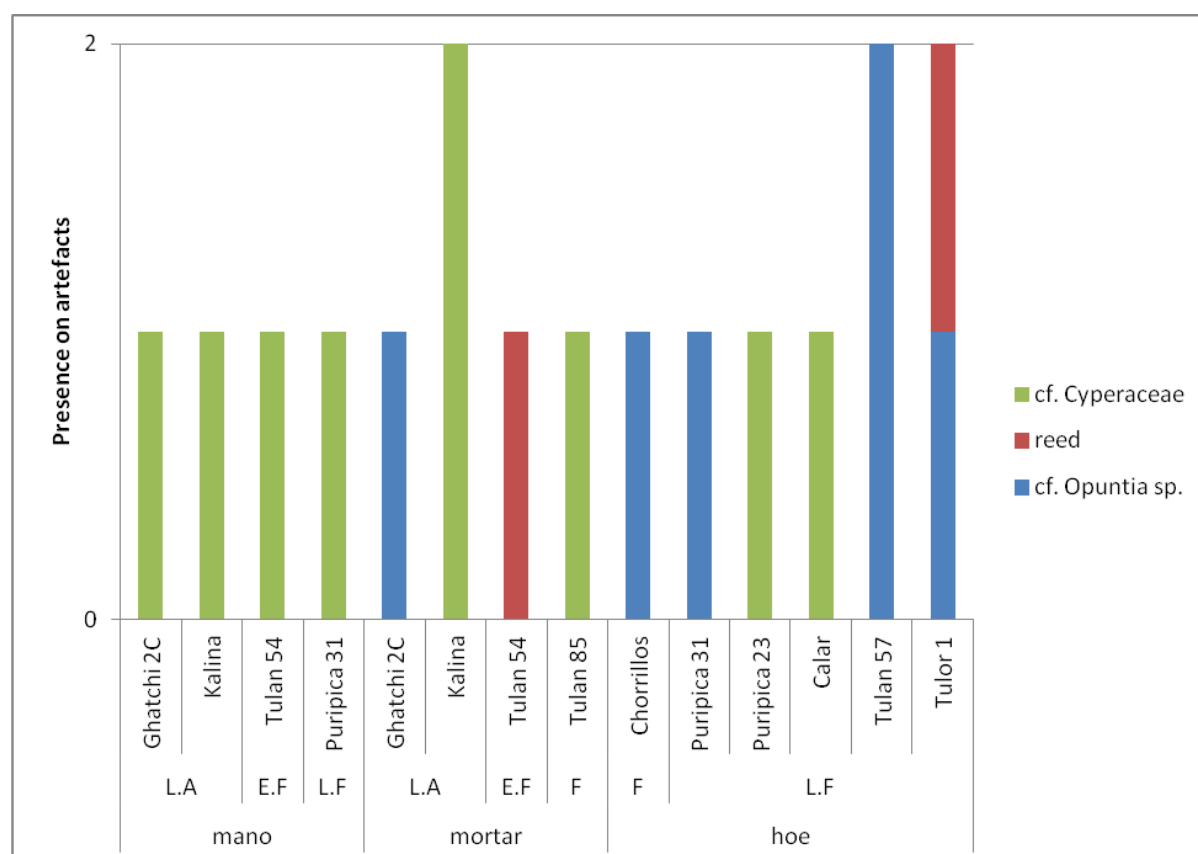


Figure 70. Artefacts with presence of phytoliths considered as cultural (LA: Late Archaic, E.F: Early Formative; L.F: Late Formative; F: Formative -represents all the Formative sub-periods-).

2. Starch grains

Regarding starch grains, I discard *Chenopodiaceae* granules due to the small size and the sometimes nebulous appearance of these agglomerates. Therefore, following the conservative approach, I will not discuss them as cultural items (Perry 2004). Also, even if not-identified (NI) starch granules can give information about the use of a tool, I will not discuss them, as I cannot rule out contamination; neither can I discuss further cultural

implications. Both are present in several sites and on grinding tools as well as on hoes (Figure 71).

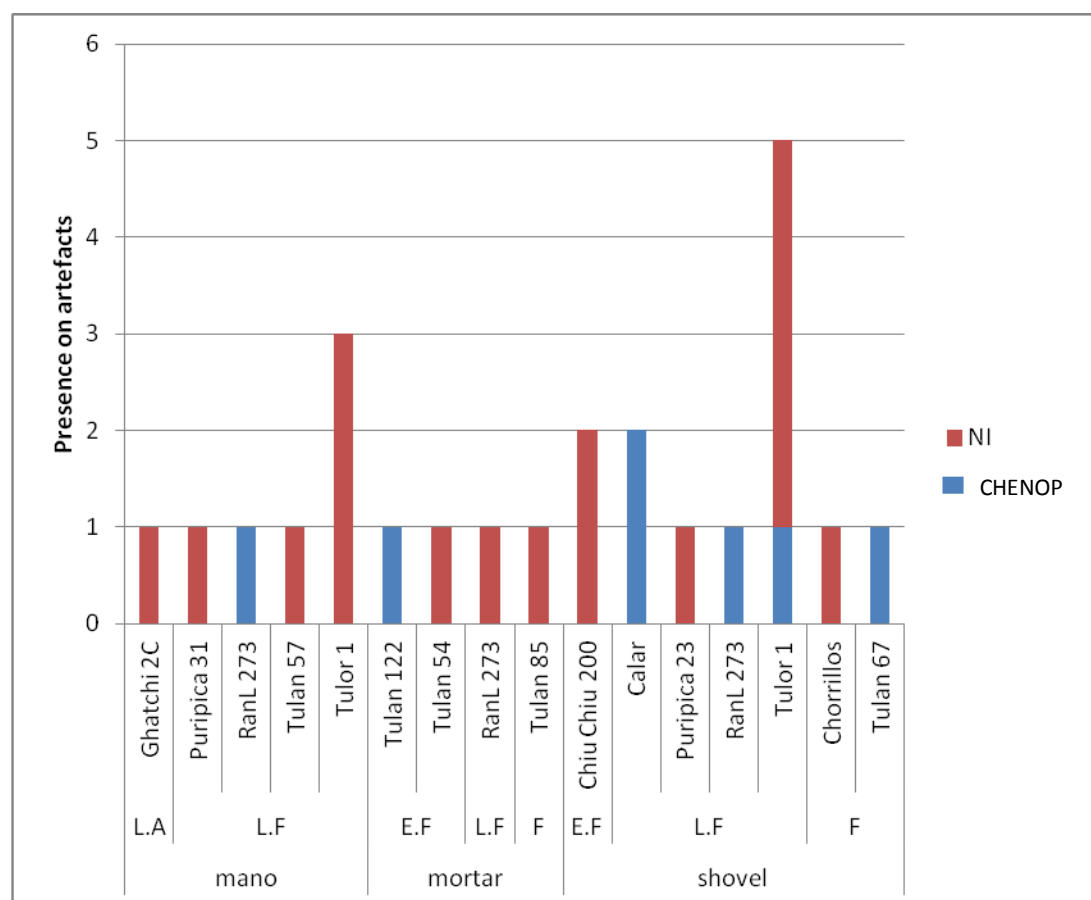


Figure 71. NI (not identified) and Chenopodiaceae starch grains (LA: Late Archaic, E.F: Early Formative; L.F: Late Formative; F: Formative -represents all the Formative sub-periods-).

Most of the resources identified by starches are economic plants that do not grow in the sites and therefore most likely to have been brought intentionally. Therefore I can discuss them as part of cultural processes within the systemic context, having in mind that in some cases their attachment to the tool could be due to a transfer from the surrounding soil matrix. Taphonomic processes of starch grains and their attachment to artefacts are still not well understood (see the discussion on taphonomic issues in CH.VII). In this sense, contamination could happen within the soil matrix or after the artefact has been recovered. Regarding the former, in 50% of the sites (n=7) there is no correspondence between the starch grain identified and the macro-remains found, although this absence could be due to taphonomic issues that decompose macro-remains (e.g., humidity in Chorrillos) and inadequate methods to recover archaeobotanical remains from these sites. The remaining

seven sites (50%) have a correspondence between micro and macro remains, though in two cases the macro-remains are unlikely to contaminate the artefacts during post-depositional events because of their scarcity, different strata and charred condition (Calar and Tulan 85). Therefore, in just five sites (Chiu Chiu 200, Tumor 1, Puripica-31, Tulan 54, Tulan 55) it could be argued that the presence of starch grains was due to contamination within the matrix, though this seems more unlikely (Table 37).

Site	Starch grain	Macro remains
Kalina	cf. <i>Hoffmanseggia</i> sp.	Nothing
Ghatchi 2C	NI	<i>Chenopodium</i> sp. (CH) <i>Asteraceae</i> , <i>Cisthante</i> , <i>Verbenaceae</i> , <i>Echinopsis</i> , <i>Tiquilia</i> , <i>Exodeconus</i> (NCH)
Tulan 55	*cf. <i>Cyperaceae</i>	<i>Zea mays</i> , <i>Cucurbita</i> sp., <i>Lagenaria siceraria</i> , <i>Chenopodium quinoa</i> , <i>Opuntia</i> sp. <i>Scirpus</i> sp., <i>Prosopis</i> sp., <i>Geoffroea decorticans</i> , <i>Tessaria absinthoides</i> , <i>Ephedra</i> sp., <i>Cortaderia</i> sp., <i>Festuca</i> sp., <i>Stipa</i> sp., y <i>Atriplex</i> sp., <i>Cyperaceae</i> CH/NCH
Tulan 54	*cf. <i>Cyperaceae</i>	<i>Opuntia</i> sp., <i>Scirpus</i> sp., scarce seeds of <i>Prosopis</i> sp, <i>Geoffroea decorticans</i> <i>Lagenaria</i> sp, cf. <i>Chenopodium quinoa</i> , <i>Atriplex</i> sp., <i>Thessaria absinthoides</i> , <i>Cortaderia atacamensis</i> CH/NCH
Chiu Chiu 200	*NI, cf. <i>Zea mays</i> /cf. <i>Prosopis</i> cf. <i>Prosopis</i> sp.	<i>Geoffroea decorticans</i> , <i>Prosopis</i> sp., <i>Zea mays</i> , <i>Lagenaria</i> sp. and <i>Gossypium</i> sp. <i>Tessaria absinthoides</i> CH/NCH
Calar	cf. <i>Hoffmanseggia</i> sp. cf. <i>Geoffroea decorticans</i>	<i>Prosopis</i> sp. (CH) <i>Cucurbitaceae</i> , <i>Geoffroea decorticans</i> , <i>Asteraceae</i> , <i>Euphorbia</i> sp., <i>Atriplex</i> sp., <i>Cisthante</i> , <i>Exodeconus</i> (NCH)
Puripica 31	*cf. <i>Prosopis</i> sp.	<i>Zea mays</i> (CH), <i>Prosopis</i> sp. (?)
Puripica 23	cf. Tuber type; cf. <i>Cyperaceae</i>	Nothing
Tulan 57	cf. <i>Cyperaceae</i>	<i>Opuntia</i> sp., <i>Geoffroea decorticans</i> (?)
Ranl 273	cf. <i>Prosopis</i> sp, cf. Tuber type, cf. <i>Prosopis</i> sp/cf <i>Zea mays</i>	Nothing
Tumor 1	*cf. <i>Prosopis</i> sp., cf. Tuber type, cf. <i>Zea mays</i> /cf. <i>Prosopis</i> <i>Cucurbita</i> sp., cf. <i>Capsicum</i> sp., <i>Cyperaceae</i>	<i>Zea mays</i> (CH) <i>Cucurbitaceae</i> , <i>Prosopis</i> sp. (NCH) <i>Geoffroea decorticans</i> (?)
Tulan 67	cf. Tuber type	<i>Geoffroea decorticans</i> , <i>Zea mays</i> , <i>Phaseolus</i> sp. CH/NCH
Tulan 85	cf. <i>Prosopis</i> sp.	<i>Zea mays</i> , <i>Cucurbitaceae</i> , <i>Prosopis</i> sp. CH/NCH
Chorrillos	cf. <i>Prosopis</i> sp, cf. Tuber type, cf. <i>Cucurbitaceae</i>	<i>Chenopodium</i> sp., <i>Chenopodiaceae</i> CH/NCH

Table 37. Association to macro-remains (CH: charred/ NCH: not charred/ ?: not mentioned in the original text; *potential contamination within matrix).

In Tular, the coincidence of both macro and micro-remains could be a product of contamination, as some of the tools (*manos* and hoes) with the presence of *Zea/Prosopis* starch were recovered from a circular structure which had multiple pits, considered as storage areas, which had *Prosopis* and maize (Llagostera *et al.* 1984). However, maize was charred and therefore their starches if still visible should exhibit taphonomical diagnostics, which they do not. *Prosopis* could be part of contamination from the matrix to the tool, though, because the starch of this specie is hard to release¹³ (Giovannetti *et al.* 2008) it seems more likely that some friction should be applied in order to get into the crevices of the artefacts sampled. Also not all of the tools sampled with the presence of these resources came clearly from the storage areas. In Pu-31 the contextual relation between macroremains and tools is not clear, neither in Chiu Chiu where the charring of the macro-remain is not specified. But in two cases, Tulan 54 and 55, where *Scirpus* macroremains are abundant, their manipulation with tools is highly probable (Holden 1991) and hence reinforces the use of this plant and the assumption that the attachment of these microfossils on stone tools relates to plant processing rather than simply the burial environment.

3. *Calcium oxalate*

Hather (2000) argues that calcium oxalate crystals are of no diagnostic value, though because *Prosopis* is positively correlated with other microfossils, I will consider it as produce by this genus and part of cultural manipulation as these trees do not grow within the area of Tulan 85 and 57 where the microfossils were identified. Cf. Chenopodiaceae in Chiu Chiu 200 could be reflecting the presence of early pseudocereals; however, Chenopodiaceae family presents different genera and species in the area (Villagrán *et al.* 1998b) and is very likely to grow as weed associated with other crops (Bruno 2006). Also their cultural or

¹³ See also Appendix 3, *Prosopis* starch.

natural attachment to tools is hard to discriminate due to their low presence. Hence I do not feel able to consider the oxalates of *Chenopodiaceae* to be a cultural indicator until more evidence corroborates its presence (Table 38).

<i>SITE</i>	<i>TOOL</i>	<i>cf Prosopis</i>	<i>Chenopodiaceae</i>	<i>Grand Total</i>
<i>Chiu Chiu 200</i>	<i>Hoe</i>		1	1
<i>Tulan 57</i>	<i>Grinding tool</i>	1		1
<i>Tulan 85</i>	<i>Grinding tool</i>	1		1
<i>Grand Total</i>		2	1	3

Table 38. Oxalates presence on sites and tools.

4. Diatoms

Diatoms are hard to assess either as part of natural or cultural consequences. In Chorrillos, where most of the majority of diatoms have been identified (48%), I think diatoms are a post-deposition occurrence because these artefacts were deposited within a moist matrix due to the occasional floods of the Loa River. In Figure 72 we can see that after Chorrillos, Tulan 85 and Tulor 1 have the highest presence of diatoms. Both sites are settled in lowland ecologies where humidity in soils can be higher than in the arid slope of ravines. Nevertheless, in arid slopes, summer rains could also create conditions for diatom deposition.

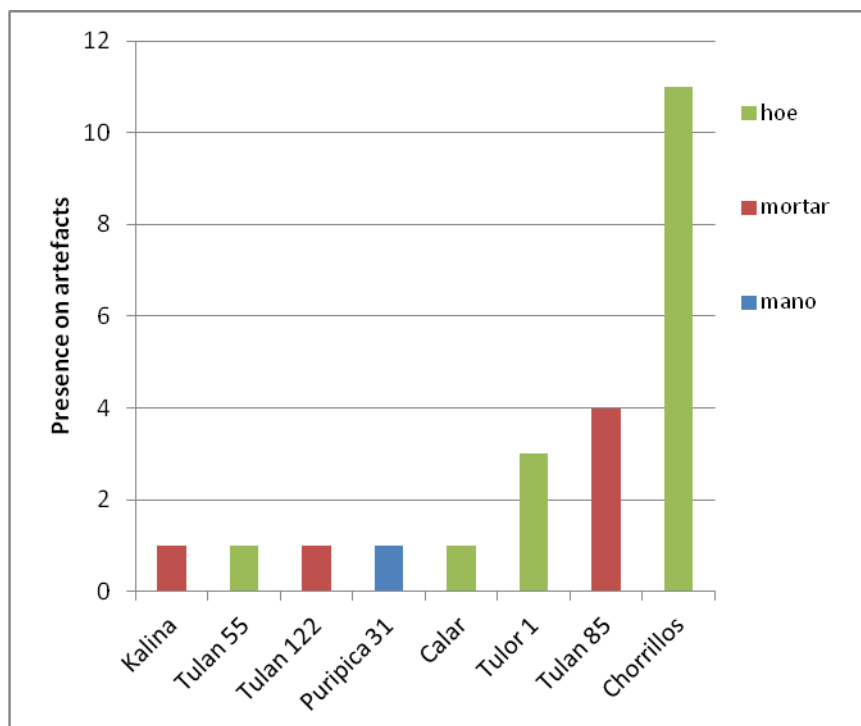


Figure 72. Presence of diatoms on sites and artefacts.

On the other hand, diatoms might be a consequence of water being used when grinding or plants might have come with diatoms attached (such as sedges). Hoes could also trap them when wet soil or water plants were manipulated. In Table 39 we can see their associations with other microfossils. Only in Kalina and Tulan 85 are diatoms associated with Cyperaceae on grinding tools, but in Tulo 1 they are only on hoes and associated with multiple microfossils. In Chorrillos they are not associated with any other identified microfossil. At this stage the lack of any clear pattern does not allow me to establish whether diatoms were caused by natural or cultural variables and therefore I shall not discuss them further.

Site	Grinding tool				Hoes					
	<i>cf. Prosopis</i>	<i>cf. Hoffmannseggia</i>	<i>Diatom</i>	<i>cf. Cyperaceae</i>	<i>cf. Prosopis</i>	<i>cf. Tuber type</i>	<i>cf. Opuntia sp.</i>	<i>cf. Cucurbitaceae</i>	<i>Diatom</i>	<i>cf. Cyperaceae</i>
Tulor					1				1	
					1	1	1	1	1	
					1				1	
Kalina		1	1	1						
Tulan 85	1		1	1						
			1							
			1							
			1							
Calar									1	
Pu-31			1							
Tulan 122			1							
Tulan 55									1	1
Grand Total	4	1	7	12	7	3	4	1	5	4

Table 39. Diatoms: association with artefacts

5. Pollen

62% of the pollen grains were identified as Poaceae and therefore most likely to be part of the surrounding environment, and so will not be considered as cultural markers.

6. Spherulites

Spherulites can be attached by tools digging into material that has animal dung as a component. This could be in context such as corrals, farming fields', piles of manure or house floors as animal dung is frequently used as a fuel for domestic cooking (Sillar 2000a). Most of the spherulites (83%) were attached to hoes rather than grinding tools, the latter being a *mano* (Figure 73). The presence of spherulites on grinding tools has been considered as evidence of contamination (Babot 2004), though I think in this case the low presence of grinding tools with spherulites (1) and the presence of spherulites mainly on hoes (5) could reflect dung manipulation, either to clean spaces or to accumulate it as fuel or as manure for the soil. All of the sites where spherulites were recovered could have been occupied permanently or sporadically by camelid herders.

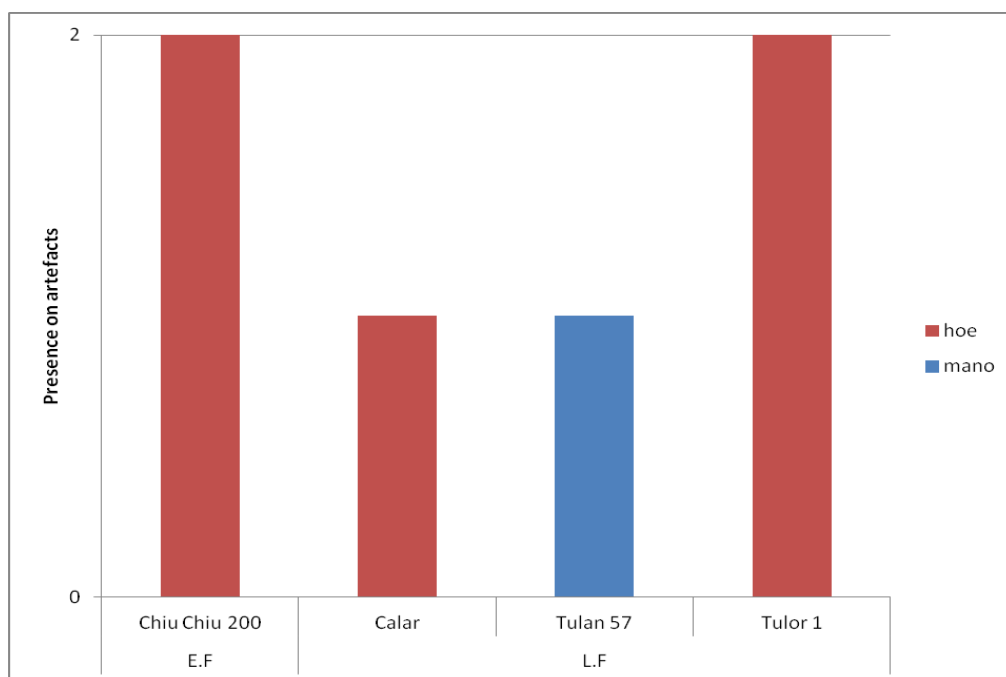


Figure 73. Artefacts with presence of spherulites per site and periods (E.F: Early Formative, L.F. Late Formative).

Regarding post-excavation contamination, I do not have precise information about how the tools were manipulated, although the fact that the artefacts present similar taxa regardless of their contexts of storage allows me to assume that these starches were caused by pre-Columbian activities (Figure 74).

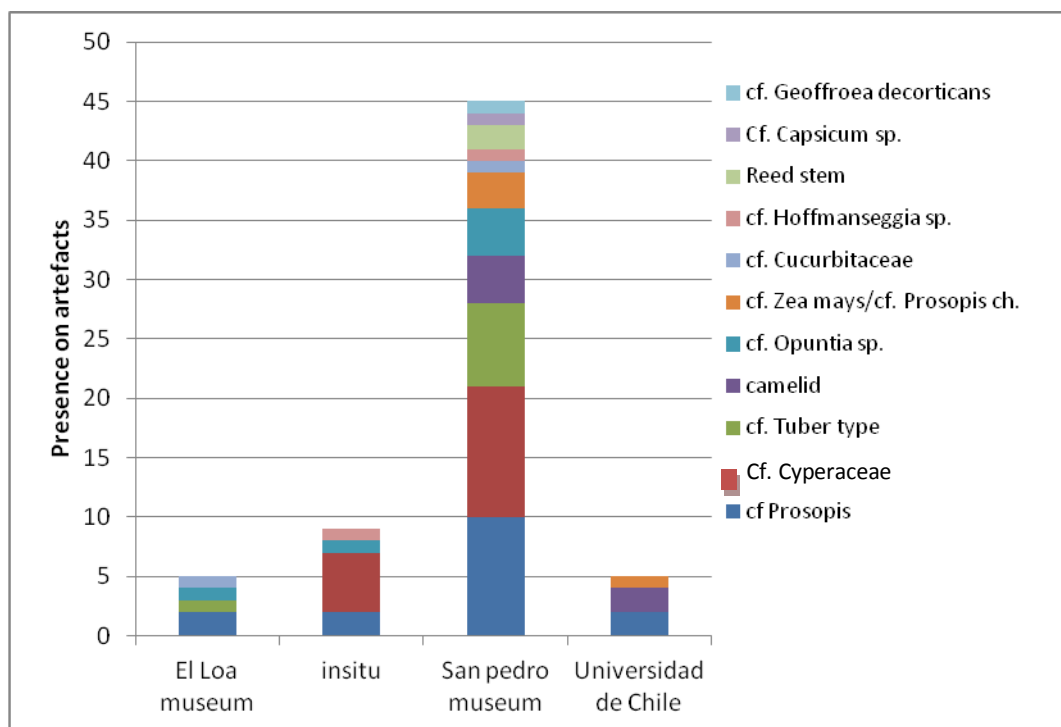


Figure 74. Similar taxa between different museums.

Concerning San Pedro museum, the higher presence reflects the fact that the main bulk of the samples were taken from there. But within the museum, the artefacts were stored in different locations (including objects left open on museum shelves, others packed in plastic bags and in different laboratories). This strengthens the idea that similar microfossils are part of a common pre-Columbian pattern rather than that the samples shared a common source of contamination. About this last point, the experiment of handling tools with gloves with maize starch (Appendix 5) showed different frequencies of starches in the tools (from three to hundreds), though these are not similar to the granules I found in my samples (Appendix 3 and 4).

c) Cultural analyses of identified microfossils

A major implication of the analysis above is that most of the species identified as “cultural” are economic plants that have a known use in the area and might have been carried to the sites intentionally. Their repetition in sites and tools, as well as their correspondence in some cases with previous archaeobotanical evidence (Table 40), allows me to propose them as part of a cultural process (e.g. within the systemic context as described by Schiffer (1972)).

						MACROREMAINS		CULTURAL MICROFOSSILS
Period	Area	Site	BC-AD BP	Grinding tools	Hoes	Crops	Wild plants	
LATE ARCHAIC	Loa	Kalina	2420-2000BC 4370-3950BP	conical mortars and manos	No	No	No	<i>Hoffmanseggia</i> sp. (sg) Cf. <i>Cyperaceae</i> (ph)
	SALAR DE ATACAMA	Ghatchi 2C	4000-3450BC 5950-5400BP	conical mortars and manos	No	No	Cactus, <i>Scirpus</i>	NI (sg) Cf. <i>Cyperaceae</i> (ph) Cf. <i>Opuntia</i> (ph)
		Tulan 52	2390-1930BC	conical mortars and manos	No	<i>Lagenaria</i> sp.	<i>Prosopis</i> , <i>Geoffroea</i> , <i>Scirpus</i> , Cactus, various	Cf. <i>Zea mays</i> (sg McRostie 2007)
		Puripica 1	2340-2100BC 4290-4050BP	conical mortars and manos	No	No	No	--

EARLY FORMATIVE	Loa	Chiu Chiu 200, Chorrillos	910-190BC 2860-2140BP	Flat, conical mortars and manos	Yes	Zea mays, Lagenaria sp., Gossipium, Chenopodium sp.	Prosopis, Geoffroea, various	Ni (sg) Cf. Zea/Prosopis (sg) Cf. Prosopis (sg) Cf. tuber type (sg) Cf. Opuntia (ph)
	SALAR DE ATACAMA	Gatchi	350BC-100AD 2300-1850BP	flat mortars and manos	Yes	Cf. Chenopodium	Scirpus, various	-
		Tulan 54, 55, 58, 67, 122	1400-400BC 3350-2350BP	flat mortars and manos	Yes	Cf. Chenopodium, Zea mays, Cucurbitaceae	Prosopis, Geoffroea, Cactus, Scirpus, tuber various	Cf. Cyperaceae (sg) Cf. tuber type (sg) Cf. Opuntia (ph) Cf. reed (ph) Cf. Zea mays (sg, McRostie 2007)
		Tulan 85	1400-400BC 3350-2350BP	Conical, flat mortars and manos	No	Zea mays Lagenaria sp.	Prosopis, Geoffroea, Scirpus, Cactus, various	Cf. Prosopis (sg) Cf. Cyperaceae (ph)
LATE FORMATIVE	Loa	Ranl 273, Chorrillos	200BC	flat mortars and manos	Yes	Lagenaria sp, Chenopodium sp.	Prosopis, Scirpus, cactus, various	Cf. Zea/Prosopis (sg) Cf. Prosopis (sg) Cf. tuber type (sg)
	SALAR DE ATACAMA	Toconao	350BC-100AD 2150-1850BP	Manos	No	Lagenaria sp.	Prosopis	-
		Tulor 1	380±65B C 200AD	flat mortars and manos	Yes	Zea mays, Lagenaria sp.	Prosopis, Geoffroea	Cf. Cucurbita sp. (sg) Cf. Zea/Prosopis (sg) Cf. Prosopis (sg) Cf. tuber type (sg)
		Tulan 57, 59, 71, 109	2330-1750BP 2450-1450BP	Flat and conical mortars and manos	Yes	Zea mays, Cucurbitaceae, Gossipium	Geoffroea, Prosopis, Opuntia	Cf. Capsicum (sg) Cf. Cyperaceae (sg)
		Tulan 82, 85	400BC-500AD 2450-1450BP	Flat mortar and manos	Yes	Zea mays, Lagenaria	Prosopis, Geoffroea	Cf. Prosopis sp. (sg) Cf. Cyperaceae (ph)
		Calar	200BC-346AD 2150-1605BP	Conical mortars	Yes	Lagenaria	Prosopis, Geoffroea, cactus	Cf. Hoffmanseggia sp (sg) Cf. Geoffroea decorticans (sg)
		Puripica 23, 31	190-80AD 1770BP	flat mortars and manos	Yes	Zea mays	Prosopis, Geoffroea	Cf. Prosopis sp. (sg) Cf. tuber type (sg) Cf. Cyperaceae (sg, ph) Cf. Opuntia (ph)

Table 40. Comparative table of macroremains and microremains (see also Table 21).

However, if their attachment to tools was a deliberate action within the systemic context, it is harder to address, as I was not able to get soil samples from the original contexts and although the scarce sediment attach to tools (identified as S.1) did not show “cultural” microfossils, the variables related to contamination within the matrix are not clear within broader taphonomic discussions. Cultural contamination in the archaeological context (in this case the museums) has either been considered unlikely or potential contaminants

discounted (as discussed above). The presence of the same taxa of plants regardless of the premises where artefacts were stored, allows me to propose that these microfossils are part of the systemic context rather than the archaeological contaminants.

Hence, the above discussion and discarding of potential non-cultural microfossils (pollen, diatoms, Chenopodiaceae oxalates, Chenopodiaceae starch grains and unidentified starch grains) is intended to:

- a) Avoid noise caused by abundant data, whose resolution will not contribute to my objectives and research questions
- b) Discuss the results in a conservative way because I do not want to overestimate the presence of specimens when I have justifiable doubts about their classification and identification.

So, from the original 150 artefacts (Table 41) (C1), just ninety-five showed positive presence of cultural and non-cultural microfossils (C2). Of these, ninety-one artefacts showed non-cultural microfossils (C3) and forty-three artefacts presented cultural microfossils (C.4). If we examine the cultural microfossils by period, the Late Archaic, Early Formative and Formative represent 18%, 27% and 19% of the original sample, whilst the Late Formative represents 38% and hence regardless of the original size of the sample, during the Late Formative the ubiquity of cultural plants seems to be higher (C5), especially because of Tular site (Figure 75). When comparing these samples between periods (C6), the Late Formative has the highest percentage of cultural microfossils (55%) and the Late Archaic, Early Formative and Formative represent lower percentages (11%, 18% and 13%). This pattern might represent both the biases in the original sampling of the artefacts and the higher ubiquity of cultural microfossils in the artefacts of the Late Formative. Therefore interpretations of abundance through time should be aware of these differences in the original sampling.

C	C1	C2	C3	C4	C5	C6
Period	Total artefacts	A. with presence of microfossils	A. with non cultural microfossils	A. with cultural microfossils	% A. with cultural microfossils within period	% A. with cultural microfossils between periods
L.A.	28	16	15	5	17.85	11.62
E.F.	28	15	9	8	28.57	18.60
F.	31	22	22	6	19.35	13.95
L.F.	63	49	45	24	38.09	55.81
	150	95	91	43		100

Table 41. Breakdown of the artefacts sampled by period and the presence of cultural and non-cultural microfossils (C: column; A: artefact).

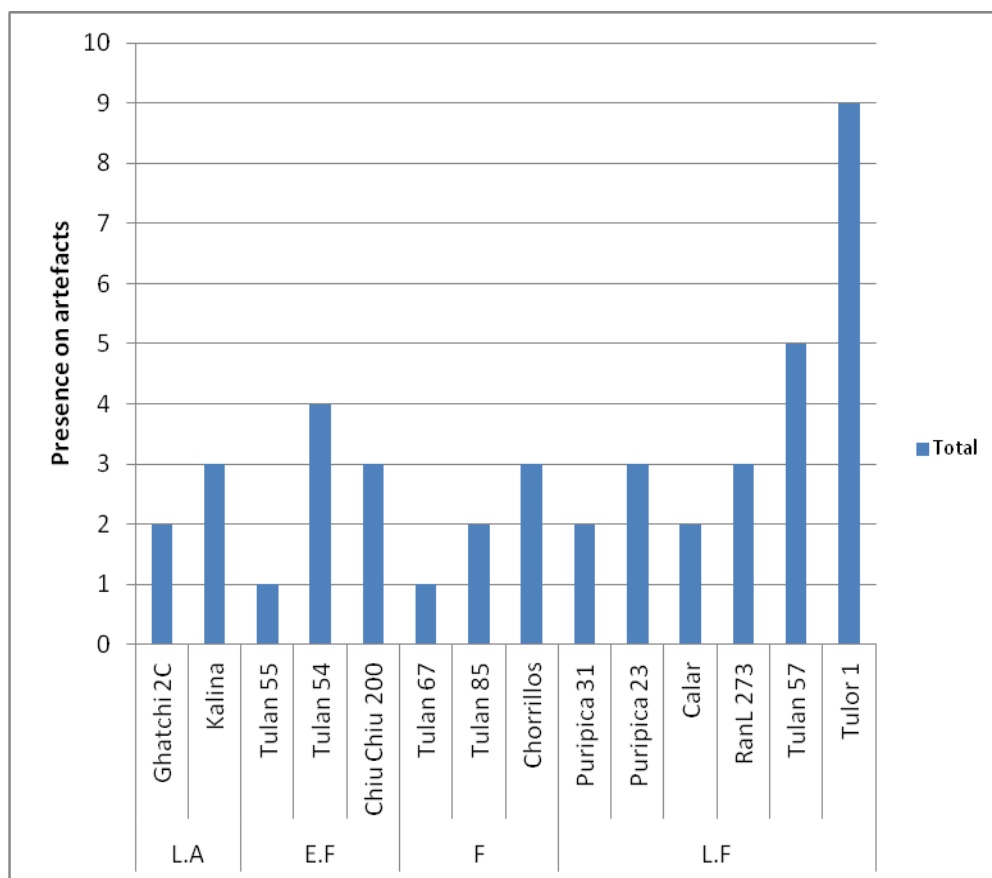


Figure 75. Number of artefacts with cultural microfossils per site and period (LA: Late Archaic, E.F: Early Formative; L.F: Late Formative; F: Formative -represents all the Formative sub-periods-).

The presence of cultural microfossils on artefacts is composed by starch grains, phytoliths, spherulites and oxalates in decreasing order (Figure 76).

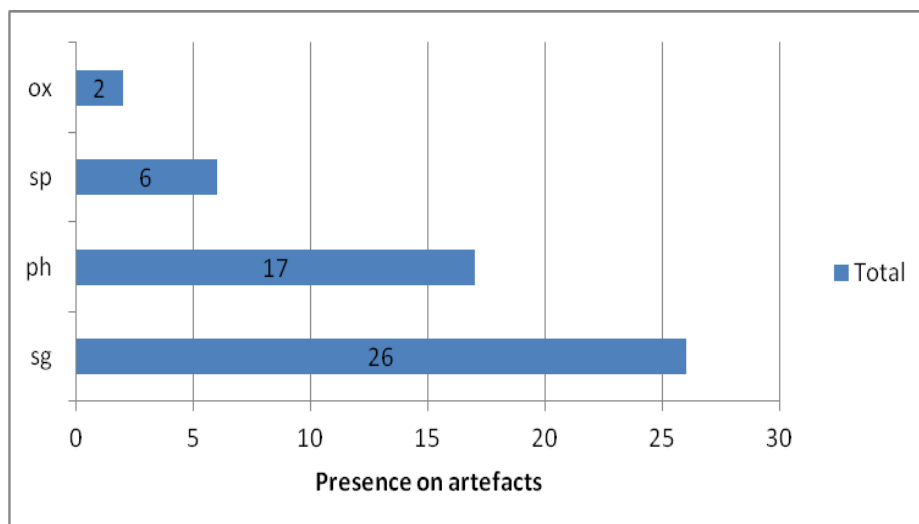


Figure 76. Artefacts with presence of different “cultural” microfossils (sg: starch grains; ph: phytoliths; sp: spherulites; ox: oxalates).

Within these “cultural” types I recognise 10 plants (Figure 77). Six were identified exclusively by starch grains: cf. *Capsicum*, cf. *Cucurbitaceae*, cf. *Geoffroea decorticans*, cf. *Hoffmannseggia* sp., cf. tuber type and cf. *Zea/Prosopis*; whilst two plants were exclusively identified with phytoliths: cf. *Opuntia* sp. and cf. reed stems. One cross checked with starch and phytoliths: cf. *Cyperaceae* and one by oxalate and starch: cf. *Prosopis*. Camelids spherulites are also discussed as cultural data.

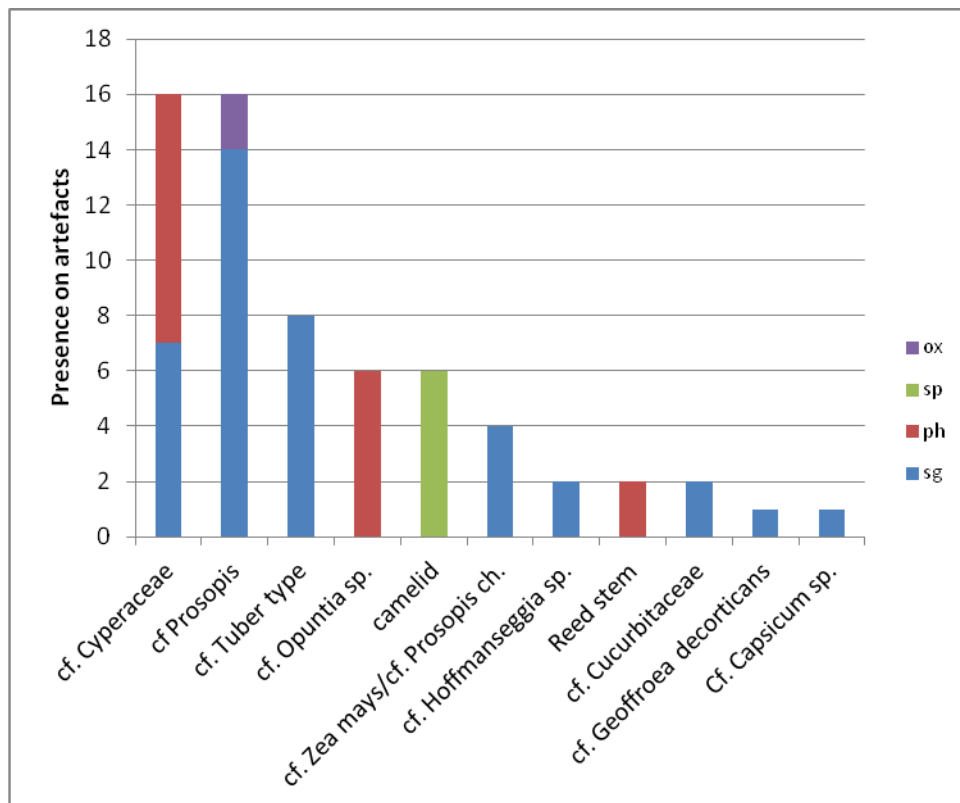


Figure 77. Presence of different taxa on artefacts according to the different microfossils (ox: oxalate, sp: spherulite, sg: starch grain, ph: phytolith).

Plants on artefacts through time and space

These taxa can be classified regarding their domestic status. Of the ten identified plants, just 20% are domestic (crops), 20% are uncertain¹⁴ and 60% are wild, which demonstrates the higher presence of wild (non-domestic) plant microfossils on the majority of these artefacts (Figure 78).

¹⁴ This category reflects microfossils that are redundant between wild and domestic plants or whose identification is too general (e.g. tuber type, and the ambiguous *Zea/Prosopis* identification).

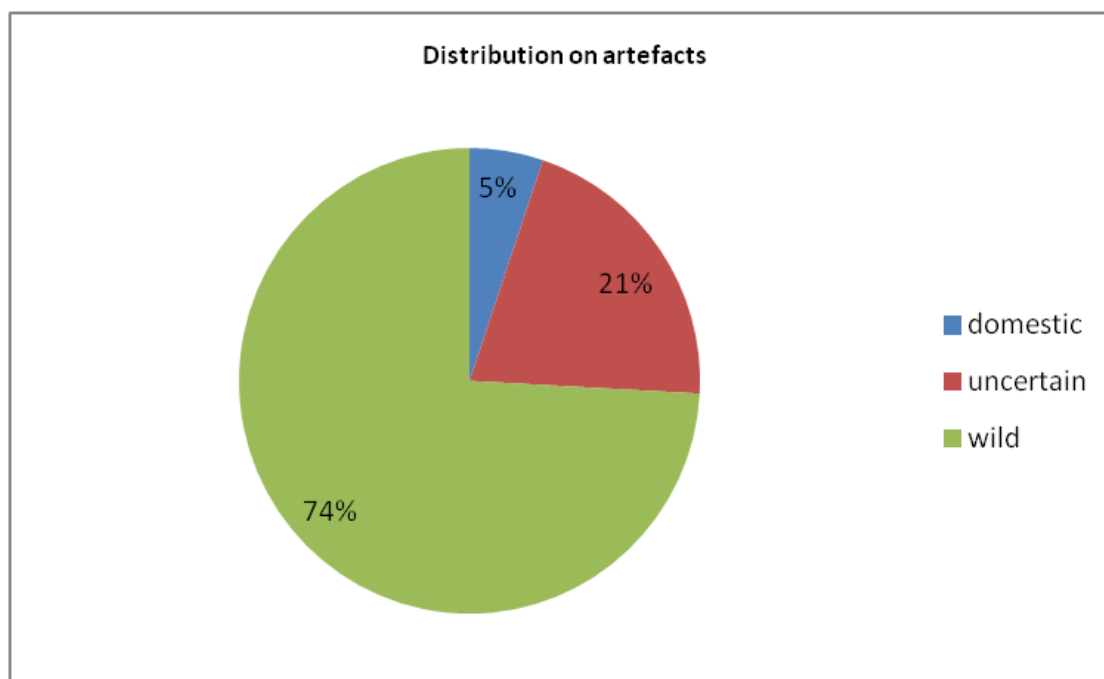


Figure 78. Presence of plants categories (domestic, uncertain, wild) on artefacts.

How do these plants microfossils relate to the artefacts and sites sampled? The identification of these plants allow us to visualise, for the first time, which resources were manipulated and processed by people using the artefacts analysed (Figure 79).

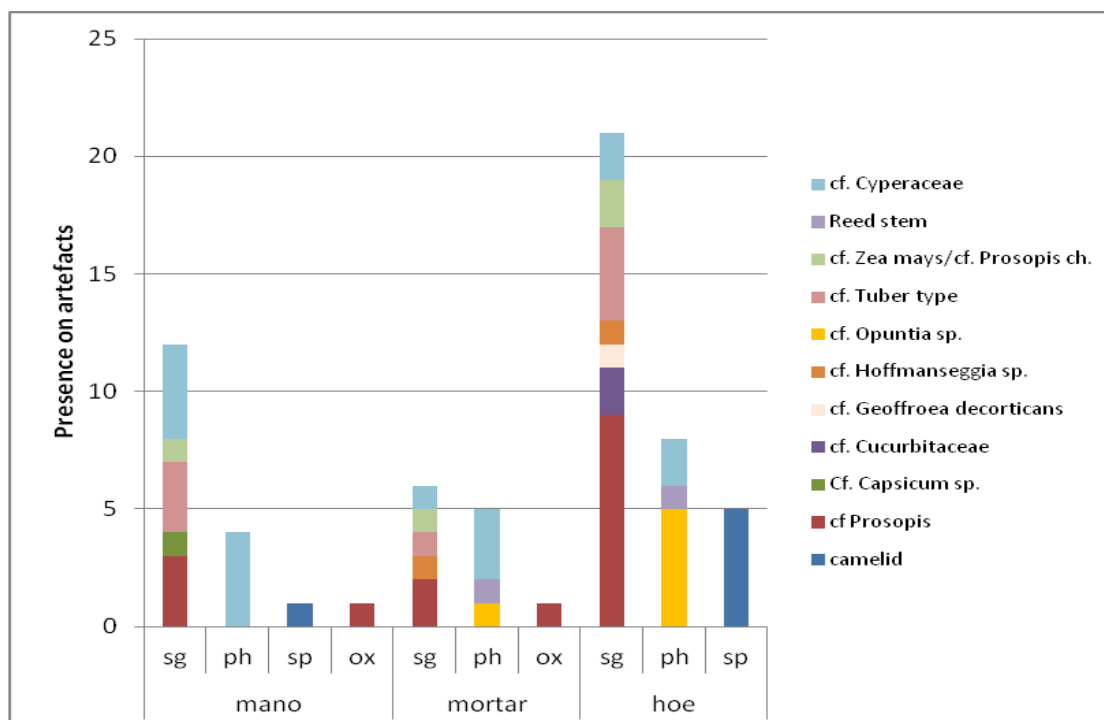


Figure 79. Types of microfossil and taxa present on hoes or grinding tools (ox: oxalates; ph: phytoliths; sg: starch grains; sp: spherulites).

As we can see, there is no exclusive or singular patterned relationship between the types of microfossils or plant taxa and the type of tools. The only exception could be camelid spherulites that are attached to five hoes compared to only one example on a *mano*. Phytoliths are distributed similarly in the different artefacts. Starch grains are present on grinding tools in almost the same proportions as on hoes. This pattern could be interpreted as contamination; however, their cultural category can be supported by the fact that they are present at different sites as well as by the fact that some taxa are starchy underground organs that are quite likely to have been dug out with hoes and subsequently processed using *manos* (Figure 80).

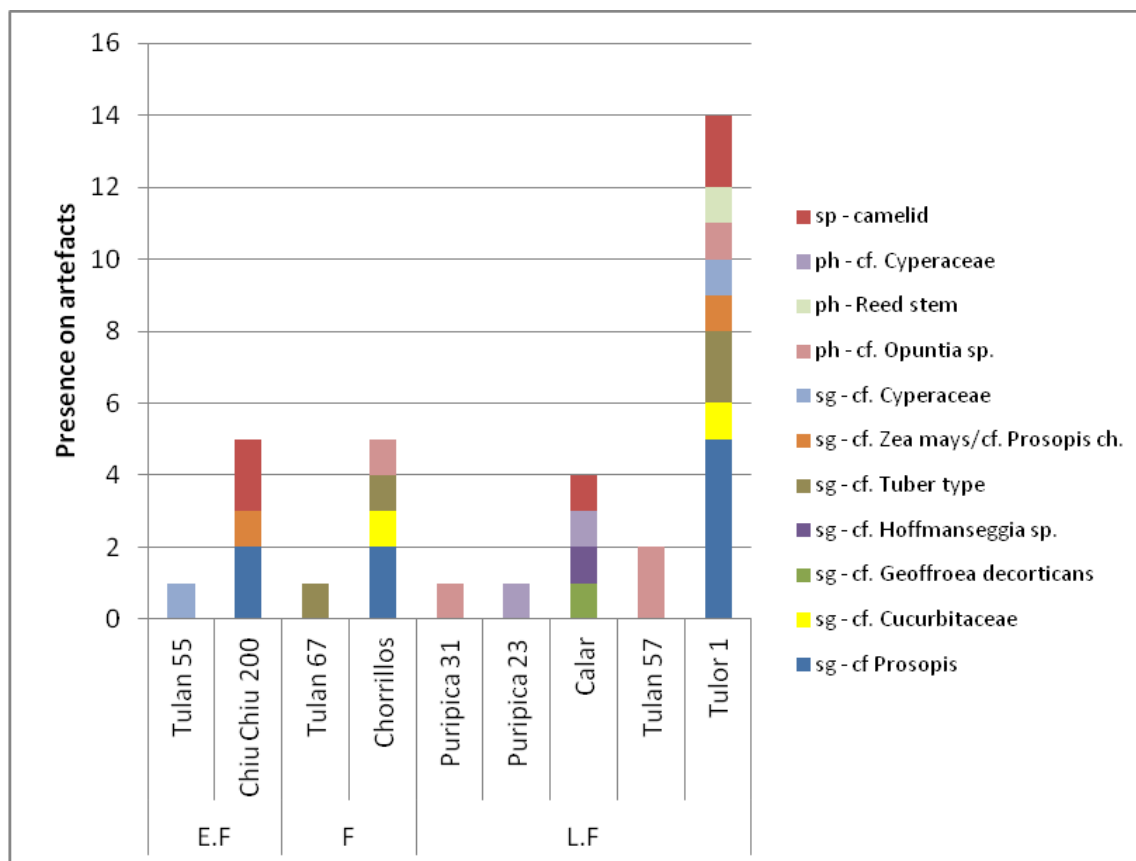


Figure 80. Distribution of taxa on hoes from different sites and periods (E.F: Early Formative; L.F: Late Formative; F: Formative- represents all the Formative sub-periods-).

At this point, it is not possible to discriminate accurately between resources processed in flat *versus* conical mortars, though resources present on the Late Archaic mortars are also present through the Formative period. Cyperaceae predominates until the Early Formative, though *Prosopis*, *Zea/Prosopis* and tuber types begin to become significant, among other minor taxa, during the Late Formative. However, camelid spherulite on a mano is probably due to contamination (Figure 81).

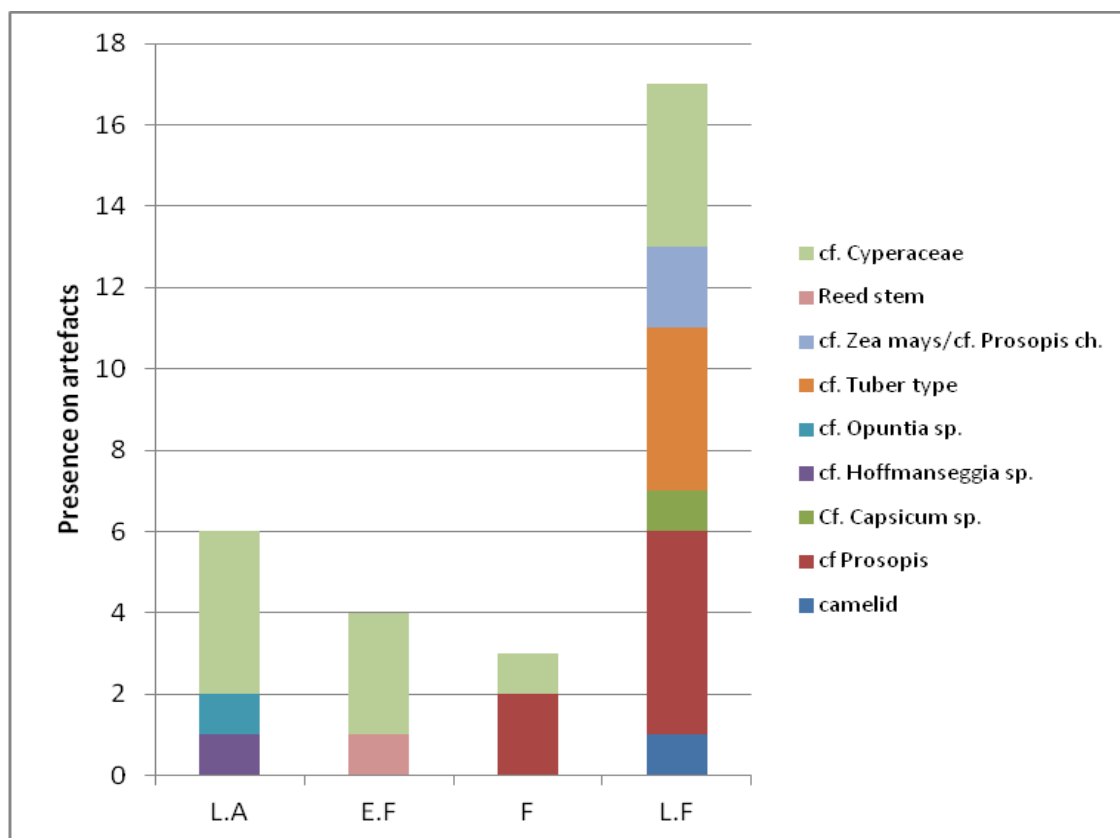


Figure 81. Distribution of taxa on grinding tools during the Late Archaic and during the Formative period: E.F: Early Formative, L.F: Late Formative, F: Formative -represents all the Formative sub-periods-).

During the Late Archaic, *Hoffmansseggia* sp., *Opuntia* sp. and Cyperaceae are present on some grinding tools on Ghatchi 2C and Kalina (samples from Puripica 1 did not have microfossils attached) (Figure 82). These plants represent ravine ecosystems where these sites and Late Archaic complex gatherers were settled.

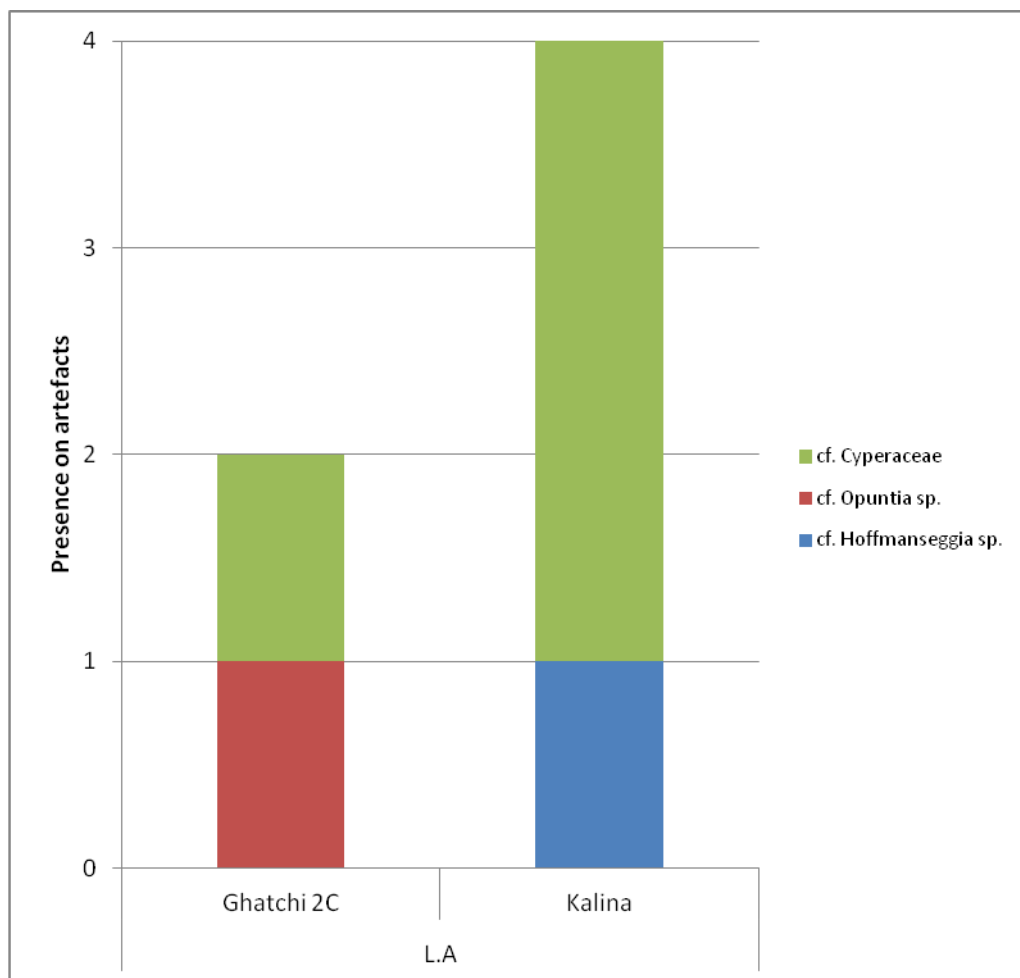


Figure 82. Taxa identified on conical mortars from Late Archaic (L.A.) sites.

During the Early Formative (Tulan 54, Tulan 55, Chiu Chiu 200), Cyperaceae and reeds are present (the latter of which could be Cyperaceae or other plants such as *Cortadera* and *Phragmites*). Cyperaceae continues throughout the Formative sequence, especially on the artefacts of ravines sites of the Salar de Atacama area (Figure 83); being the second most ubiquitous resource during the Formative period (Figure 84). *Prosopis* is present in 50% of the sites of the Formative period, especially in the oases sites (Chiu Chiu-200, Chorrillos, Ranl 273, Tumor 1) (Figure 83) and *Prosopis* appears to be the dominant resource during the Formative period (Figure 84), although this pattern is partly due to its high presence at Tumor 1 (Figure 85).

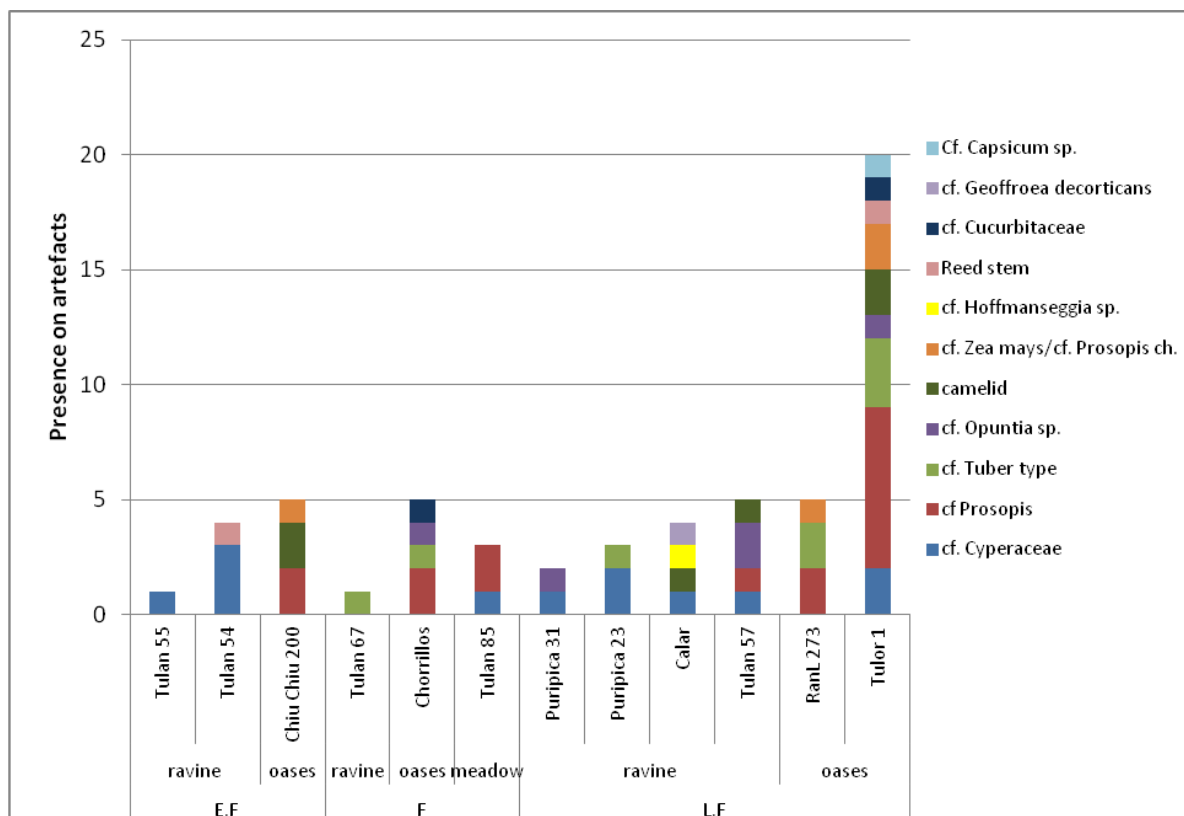


Figure 83. Presence of taxa on artefacts from sites- and their respective ecosystem location - (E.F: Early Formative, L.F: Late Formative and F: Formative represents all the Formative sub-periods).

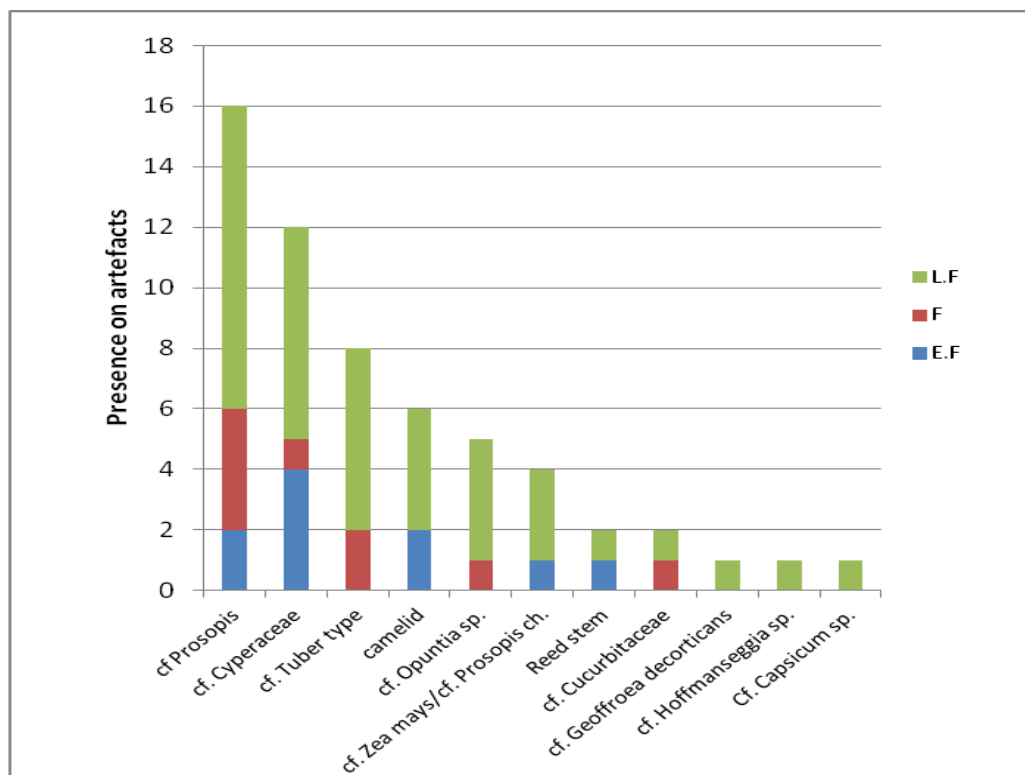


Figure 84. Presence of taxa on artefacts within the Formative sequence (EF: Early Formative, L.F: Late Formative and F: Formative -represents all the Formative sub-periods).

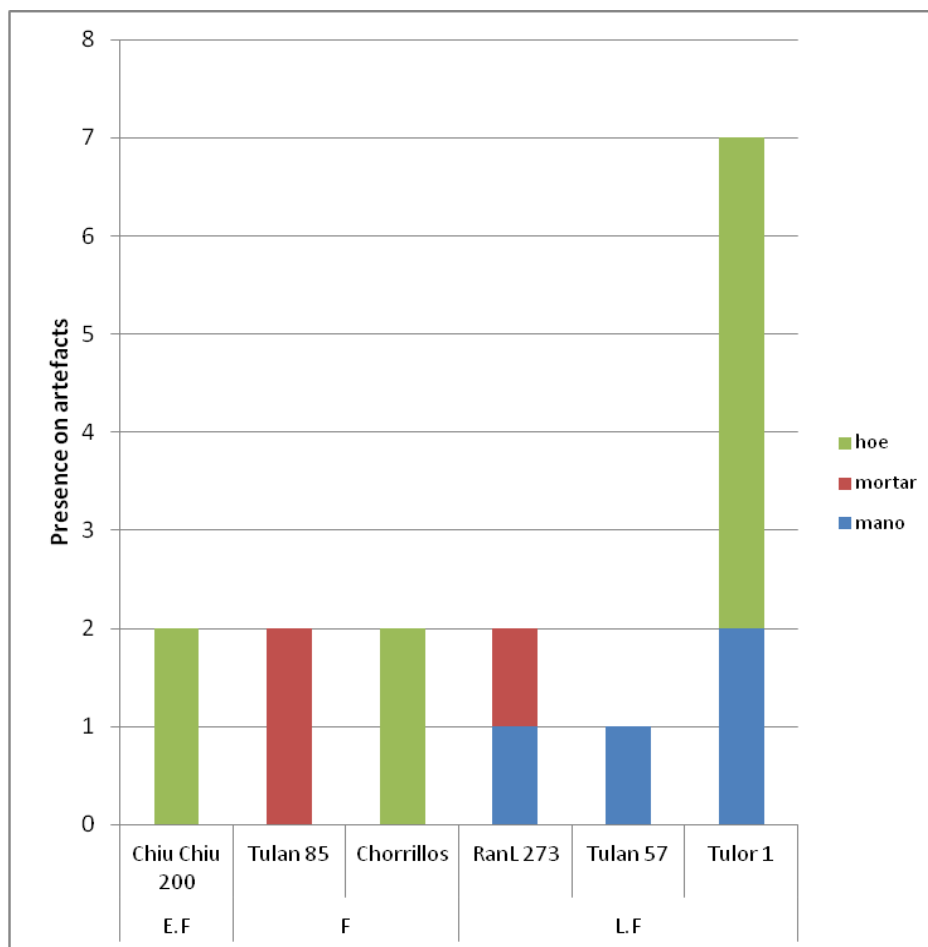


Figure 85. Distribution of *Prosopis* on artefacts from Formative sites (EF: Early Formative, L.F: Late Formative and F: Formative -represents all the Formative sub-periods).

Tubers are present in Formative sites from the oases (Tular 1, Chorrillos) and river/streams (Puripica 23, Tulan 67, Ranl 273); on *manos*/mortars as well as on hoes (Figure 86). However, only the starch grain found in Chorrillos resembles the *Solanum tuberosum* type (Figure 87) and therefore this reflects a difference from the bell type starches found on the other sites, which are not diagnostic.

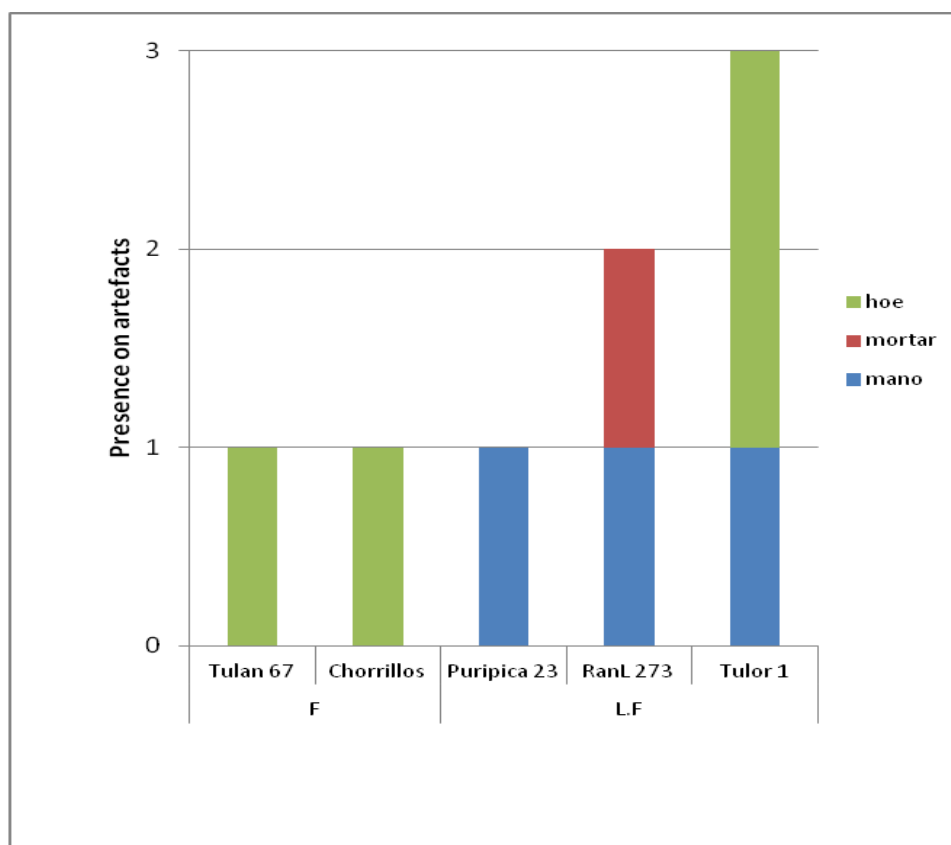


Figure 86. Distribution of tuber types on artefacts from Formative sites (L.F: Late Formative and F: Formative -represents all the Formative sub-periods).

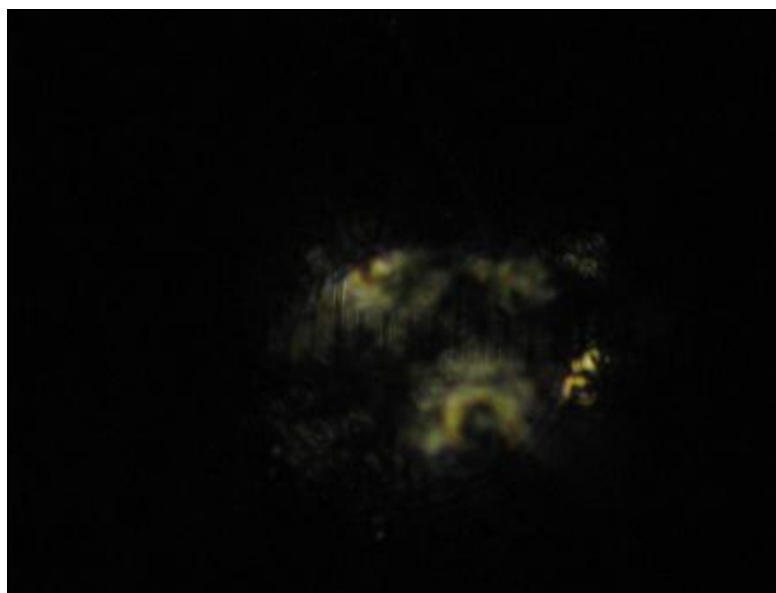


Figure 87. *Solanum* type found in Chorrillos.

Zea/Prosopis is present at the Early Formative site Chiu Chiu 200, the Late Formative site Tumor 1 and Ranl 273; all of them located in oases areas. In Tumor 1 as well as in Chiu Chiu,

the presence of maize and *Prosopis* as macro-remains do not help to resolve the uncertain category of these starches nor the circumstances of their attachment to tools (see Table 37).

Finally, crops are only present in the Formative sites Tular 1 and the Chorrillos cemetery, though in low quantities and as species not considered to be main staples (*Capsicum* and Cucurbitaceae) (Figure 88). Cucurbitaceae (cf. *Lagenaria* sp) is present only in hoes and *Capsicum* on a *mano*.

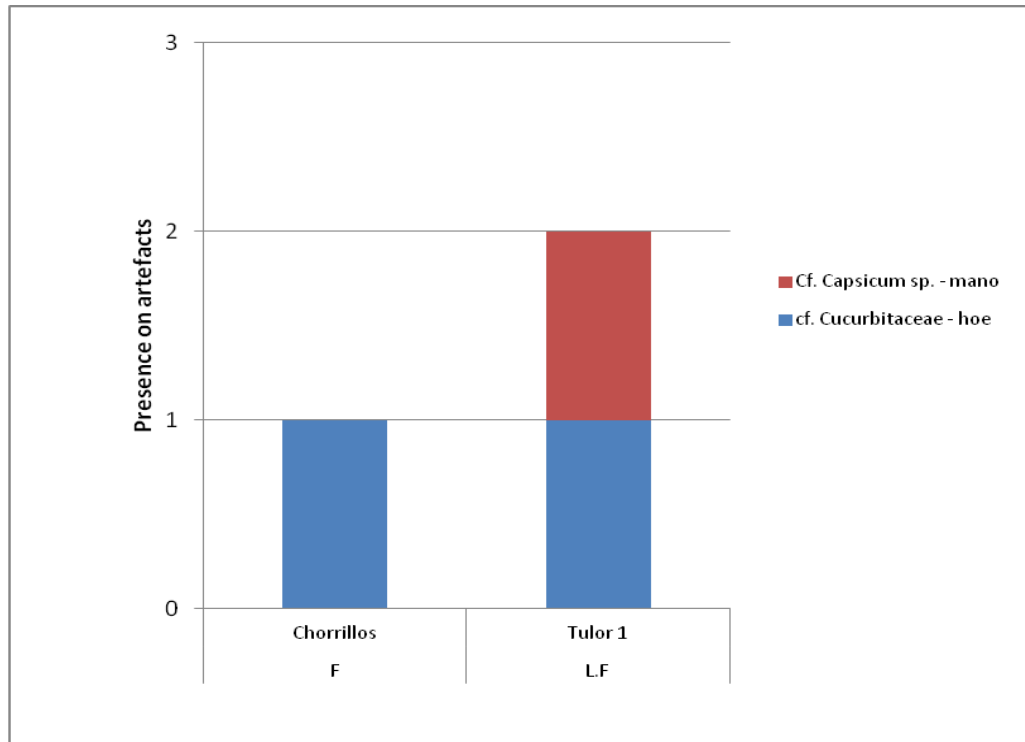


Figure 88. Crops present on artefacts from Formative sites (L.F: Late Formative and F: Formative -represents all the Formative sub-periods).

With these results, neither agriculture of maize nor any other kind of agriculture that has been proposed for the Formative period is strongly supported.

Some major trends in time and space that are evident in the data are that wild plants have the highest presence throughout the sequence including in the Late Formative. As we can see in Figure 89, during the Late Archaic period, only wild plants were identified, whilst uncertain types and domestic types are introduced in lower numbers during the Formative period, but wild plants still predominate to the end of the Formative.

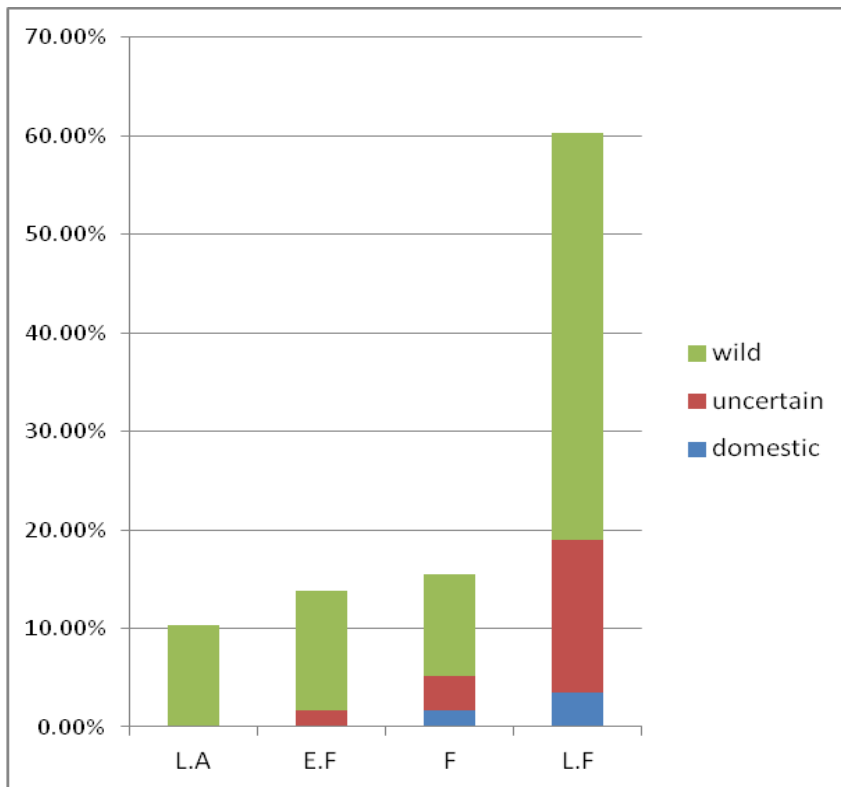


Figure 89. Plant categories (wild, domestic, uncertain) through periods (L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative; F: Formative represents all the Formative sub-periods).

Another pattern is that those sites located in the streams of the Salar de Atacama use mainly plants from nearby streams and rivers; hence, Archaic populations are grinding local riverine/ravine resources (*Cyperaceae*, *Opuntia*) rather than oases resources. This pattern seems to continue during the Formative period where riverine resources (*Cyperaceae*, *Opuntia*) predominate on artefacts at sites located in this ecosystem (Tulan, Puripica, Calar) whilst other resources such as crops, tuber types and *Prosopis* are more represented at the oases sites (Tulor, Chorrillos, Ranl, Chiu Chiu) rather than gorges, although this pattern is not totally exclusive (Figure 90).

However, there is no correlation between tools and resources and the question of whether the attachments of microfossils to tools are indeed exclusively a consequence of cultural manipulation remains open to further exploration of taphonomic analyses. Nevertheless, at this stage the microfossils defined as cultural; can at least be discussed as part of the systemic context and hence of human-plant interactions.

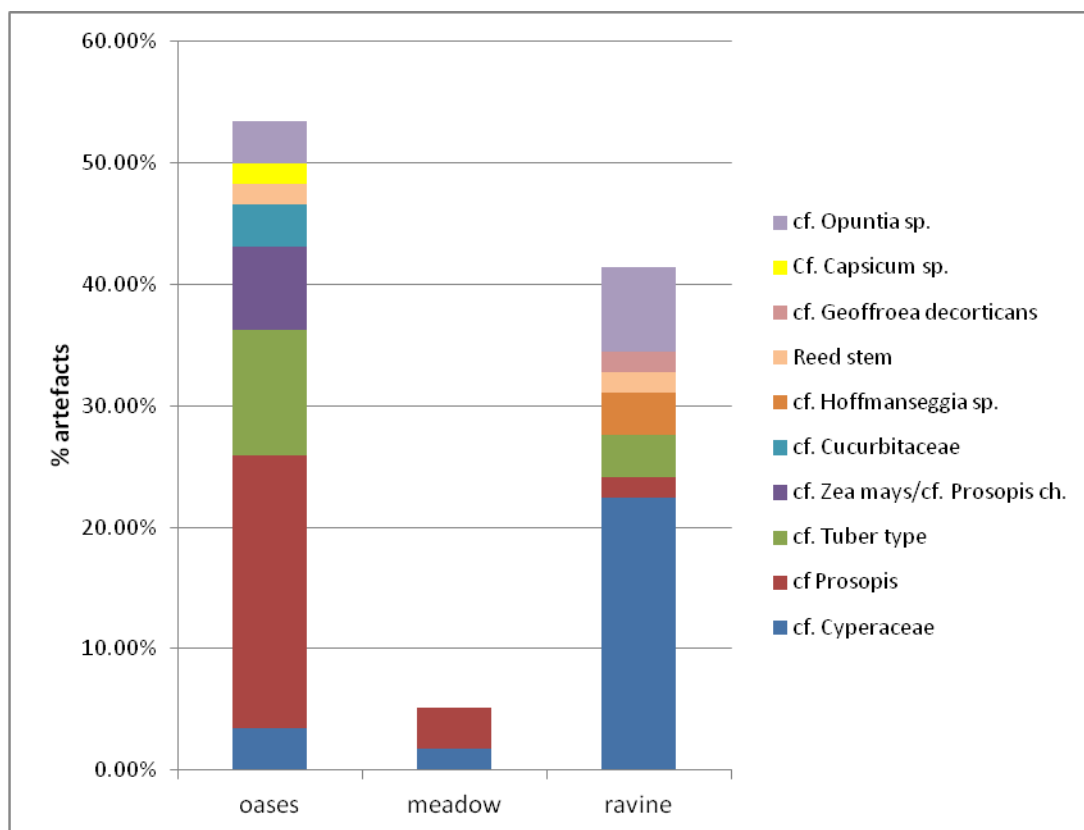


Figure 90. Plant taxa in relation to the ecosystem of the sites where they were found.

VIII.2 Isotopes

Reference collection and local baseline

$\delta^{13}C_{col}$, $\delta^{13}C_{ap}$ and $\delta^{15}N$

The mean of the available isotopic information for plants in Paso Jama (3500-4000masl) and the Socompa transect (4000-3000masl) in the Atacama Desert plus the thirteen species sampled in this research (BEIF, original data Bloomsbury Isotope Facility University College London) will be used to establish the plant baseline (Table 42) (Ehleringer *et al.* 1992; Kraus *et al.* 2001; Quade *et al.* 2007).

FAMILY	GENUS/SPECIE	&13C	1.5	&15N	REFERENCE	PP
Asteraceae	<i>Artemisia copa</i>	-21.6	-20.1		Quade et al 2007	C3
Asteraceae	<i>Doniophyton cf. Weddellii</i>	-27.9	-26.4		Quade et al 2007	C3
Asteraceae	<i>Haplopappus rigidus</i>	-21.7	-20.2		Quade et al 2007	C3
Asteraceae	<i>Parastrephia lepidophylla</i>	-20.66	-19.16		Quade et al 2007	C3
Asteraceae	<i>Pluschea sp.</i>			7.2	Ehleringer et al. 1992	
Asteraceae	<i>Senecio aff. nutans</i>	-22.77	-21.27		Quade et al 2007	C3
Boraginaceae	<i>Phacelia cummingii</i>	-23.3	-21.8		Quade et al 2007	C3
Cactaceae	<i>Opuntia sp.</i>	-11.2	-9.7		Quade et al 2007	C4/CAM
Cactaceae	<i>Opuntia sp.</i>	-14.14	-12.64		Quade et al 2007	C4/CAM
Cactaceae	<i>Opuntia sp.</i>	-9.21	-7.71	3.54	BEIF	C4/CAM
Cactaceae	<i>Opuntia sp.</i>	-12.06	-10.56		Kraus et al 2001	C4/CAM
Cactaceae	<i>Opuntia sp.</i>	-12.37	-10.87		Kraus et al 2001	C4/CAM
Cactaceae	<i>Trichoceurus sp.</i>	-9.46	-7.96	9.46	BEIF	C4/CAM
Chenopoidaceae	<i>Atriplex imbricata</i>	-14.14	-12.64		Quade et al 2007	C4
Chenopoidaceae	<i>Atriplex imbricata</i>	-15.2	-13.7		Quade et al 2007	C4
Chenopoidaceae	<i>Atriplex imbricata</i>	-12.43	-10.93	9.62	BEIF	C4
Chenopoidaceae	<i>Chenopodium quinoa</i>	-24.92	-23.42	8.38	BEIF	C3
Cyperaceae	<i>Scirpus sp.</i>	-27.07	-25.57	2.53	BEIF	C3
Ephedreaceae	<i>Ephedra sp.</i>	-22.1	-20.6		Quade et al 2007	C3
Fabaceae	<i>Adesmia melanthes</i>	-21.8	-20.3		Quade et al 2007	C3
Fabaceae	<i>Adesmia spinosissima</i>	-22.5	-21		Quade et al 2007	C3
Fabaceae	<i>Geoffreoa decorticans</i>	-26.29	-24.79	-0.68	BEIF	C3
Fabaceae	<i>Hoffmannseggia sp.</i>	-23.46	-21.96	1.17	BEIF	C3
Fabaceae	<i>Lupinus</i>	-22.76	-21.26		Quade et al 2007	C3
Fabaceae	<i>Phaseolus sp.</i>	-28.26	-26.76	-1.9	BEIF	C3
Fabaceae	<i>Prosopis sp.</i>	-26.19	-24.69	5.25	BEIF	C3
Fabaceae	<i>Prosopis alba</i>			0.3	Ehleringer et al. 1992	
Fabaceae	<i>Prosopis tamarugo</i>			0.4	Ehleringer et al. 1992	
Malvaceae	<i>Cristaria andicola</i>	-24.2	-22.7		Quade et al 2007	C3
Poaceae	<i>Chuquiraga atacamensis</i>	-21.29	-19.79		Quade et al 2007	C3
Poaceae	<i>Cortaderia atacamensis</i>	-23.65	-22.15	0.97	BEIF	C3
Poaceae	<i>Distichlis spicata</i>	-13.1	-11.6	2.25	BEIF	C4
Poaceae	<i>Distichlis spicata</i>			6.7	Ehleringer et al. 1992	
Poaceae	<i>Stipa frigida</i>	-22.8	-21.3		Quade et al 2007	C3
Poaceae	<i>Stipa/Festuca</i>	-24.59	-23.09		Quade et al 2007	C3
Poaceae	<i>Zea mays</i>	-13.21	-11.71		BEIF	C4
Poaceae	<i>Zea mays</i>	-13.22	-11.72		BEIF	C4
Poaceae	<i>Zea mays</i>	-13.17	-11.67		BEIF	C4

Polimoneaceae	<i>Gilia crassifolia</i>	-23.3	-21.8		Quade et al 2007	C3
Portulacaceae	<i>Cistanthe amaranthoides</i>	-21.3	-19.8		Quade et al 2007	C3
Portulacaceae	<i>Cistanthe salsoloides</i>	-22.9	-21.4		Quade et al 2007	C3
Portulacaceae	<i>Cistanthe sp.</i>	-14.08	-12.58	10.37	BEIF	C4
Solanaceae	<i>Baccharis tola</i>	-20.71	-19.21		Quade et al 2007	C3
Solanaceae	<i>Fabiana denudata</i>	-21.51	-20.01		Quade et al 2007	C3
Solanaceae	<i>Jaborosa parviflora</i>	-22.5	-21		Quade et al 2007	C3
Solanaceae	<i>Reyesia parviflora</i>	-21.6	-20.1		Quade et al 2007	C3
Verbenaceae	<i>Junellia seriphioides</i>	-20.38	-18.88		Quade et al 2007	C3

Table 42. $\delta^{13}\text{C}$ +1.5 carbon industrial effect added to modern samples and $\delta^{15}\text{N}$ values for local plants.

Almost all the plants are C3 (84.2%), though CAM and C4 plants are also present (*Trichoceurus sp.*, *Opuntia sp.*, *Atriplex imbricate*, *Distichlis spicata*, *Cistanthe sp.* and *Zea mays*). C4/CAM plants have an average of -11.14‰ (range -7.9‰ to -13.7‰). C3 plants have an average of -21.74‰ (range -18.88‰ to -26.76‰). C4/CAM and C3 values are within global ranges for these plants (-10‰ to -14‰ and -34‰ to -20‰ respectively) (Barberena 2002), though the average of all C3 plants is higher than the global average of -27‰ (Quade et al. 2007) or -26‰ (range -19‰ to -26‰) in the Argentinian Puna (Fernández et al. 1991; Panarello et al. 2006-2009).

Also C4/CAM values are slightly higher (-11.14‰) than previously reported for the area (-14.45‰). This might be because the values for *Opuntia* and *Atriplex* are higher than previously reported (Quade et al. 2007) and other CAM/C4 species have been included (*Trichoceurus sp.*, *Zea mays*). The local *Zea mays* is within expected values for C4 plants (-12 to -16‰), though it has a lower value (-13‰) than previous reports for the southern Andes (Falabella et al. 2007; Gil et al. 2009; Hastorf 1991; Korstanje 2005).

The average value of nitrogen in plants is $\delta^{15}\text{N}$ 4.09‰ with a range between -1.9‰ and 10.37‰ (Leguminoseae plants have a mean of 0.75 whilst non-Leguminoseae have a mean of 6.10). Twenty-four percent of the species have values above 5‰. These values for plants are higher than values reported for the northern coast of Chile, which mostly range between $\delta^{15}\text{N}$ of 2.9‰ and 5.8‰ (Tieszen & Chapman 1992). These could be explained due to the lack of soil crust in this desert area (Coltrain et al. 2006) and the arid conditions of the area (Bustamante et al. 2004). For eight camelids, we have a $\delta^{13}\text{C}$ ranging between -12.6‰ and -16.8‰ and a $\delta^{15}\text{N}$ between 7‰ and 13.3‰ (López 2010).

To analyze human diet, I will consider the average dietary value ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) of the local plants and local camelids (Table 43 and Figure 91).

Period	Plant	Range $\delta^{13}\text{C}\text{‰}$	Range dietary value $\delta^{13}\text{C}\text{‰}$ (+1.5)	Average $\delta^{13}\text{C}\text{‰}$	Average dietary $\delta^{13}\text{C}\text{‰}$ (+1.5)	Average $\delta^{15}\text{N}\text{‰}$	Average dietary value $\delta^{15}\text{N}\text{‰}$
Modern	C3 plants	-20.38 to -28.26	-18.88 to 26.76	-23.24	-21.74	2.7	5.7
Modern	C4/CAM plants	-9.21 to -15.2	-7.71 to -13.7	-12.64	-11.14	7	10
Period	Animal	Bone	-2‰ $\delta^{13}\text{C}\text{‰}$ flesh	Average bone $\delta^{13}\text{C}\text{‰}$	Average flesh $\delta^{13}\text{C}\text{‰}$	Average $\delta^{15}\text{N}\text{‰}$	Average dietary value $\delta^{15}\text{N}\text{‰}$
Formative	Camelid	12.6 to 16.8	14. to 18.8	-14.93	-16.93	10.76	13.76

Table 43. Calculated from the samples' $\delta^{13}\text{C}$ values, +1.5‰ carbon industrial effect added to contemporary samples, -2‰ subtracted from bone samples to estimate animal flesh and +3‰ added to $\delta^{15}\text{N}$ for trophic-level effect. Adapted from (Tykot et al. 2009, 163).

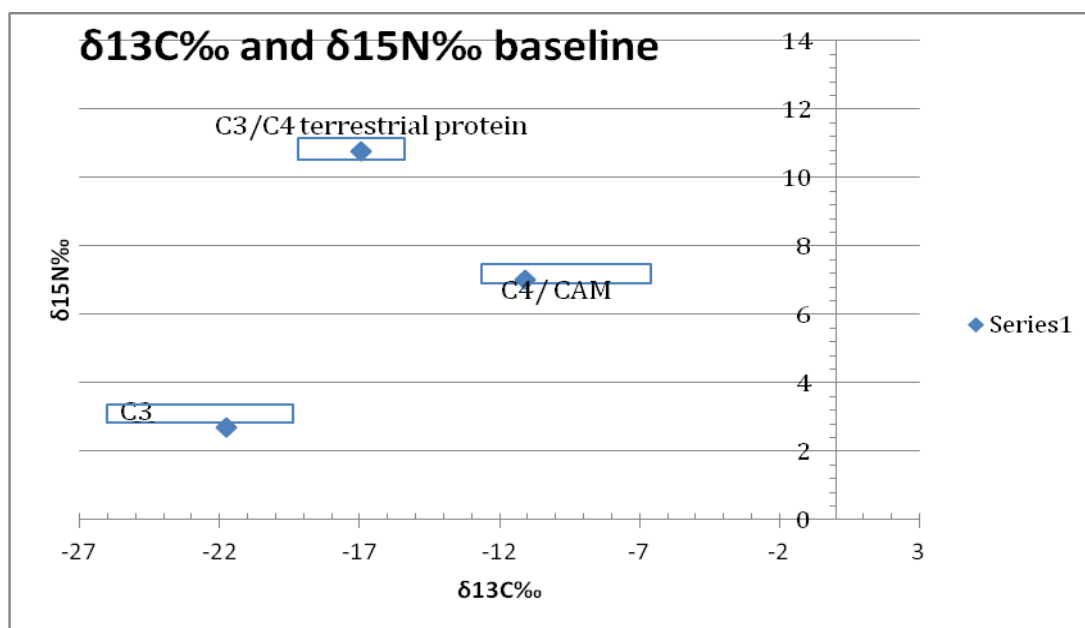


Figure 91. $\delta^{13}\text{C}\text{‰}$ and $\delta^{15}\text{N}\text{‰}$ reference baseline.

Camelids, which represent the main bulk of terrestrial protein, have $\delta^{15}\text{N}$ mean values of 10.76, which mean that for human diet (13.76‰) nitrogen values are higher than global terrestrial values. These high values can be explained by the arid conditions of Atacama, which optimise the extraction of nitrogen by animals (Ambrose 1993). A similar situation has been reported in herbivores of arid Eastern Africa and South Africa, where $\delta^{15}\text{N}$ values are similar to marine ones (+12‰ to +19‰) (Ambrose & De Niro 1986). Therefore,

differentiation between a marine and a terrestrial diet is not possible based on this isotope in arid areas (Sealy *et al.* 1987) and needs to incorporate the $\delta^{13}\text{C}_{\text{ap}}$ and $\delta^{13}\text{C}_{\text{col}}$ as well as other archaeological evidence.

The average isotopic endpoint of an entirely terrestrial vegetarian C3 diet (corrected for the industrial effect) is -21.74‰, while the average of C4/CAM is -11.1‰. This means a 10.64‰ spacing (Table 44) to model a conversion table in order to estimate the percentage of C4 in diets in this region (Tykot *et al.* 2009). Considering fractionation models, I will use the traditional +5.1‰ between diet and bone collagen (Ambrose *et al.* 1997; Pate 1994). However, as the fractionation between apatite and diet is not so clear, I will also discuss the alternative +9.4‰ (Ambrose & Norr 1993; Tieszen & Fagre 1993) and +12‰ models (Harrison & Katzenberg 2003; Schwarcz 2006) (see methodological chapter).

$\delta^{13}\text{C}$	% C4 diet	$\delta^{13}\text{C}_{\text{col}}+5.1$	$\delta^{13}\text{C}_{\text{ap}}+12$	$\delta^{13}\text{C}_{\text{ap}}+9.4$
-21.74	0	-16.64	-9.74	-12.34
-20.67	10	-15.64	-8.74	-11.34
-19.69	20	-14.64	-7.74	-10.34
-18.54	30	-13.64	-6.74	-9.34
-17.48	40	-12.64	-5.74	-8.34
-16.42	50	-11.64	-4.74	-7.34
-15.35	60	-10.64	-3.74	-6.34
-14.29	70	-9.64	-2.74	-5.34
-13.22	80	-8.64	-1.74	-4.34
-12.16	90	-7.64	-0.74	-3.34
-11.1	100	-6.64	0.26	-2.34

Table 44. Theoretical model of C3/C4 plant consumption base in the average of C3/C4 local plants and isotopic diet with +5.1, +9.4/+12 fractionation models. Adapted from Tykot (2009, 165).

There is a difference of 30‰ between the two apatite fractionation models, which is relevant in the interpretation of the consumption of C4 plants (primarily maize), as the proportion of C4 versus C3 plants in the diet would be more apparent in apatite than in collagen (Harrison & Katzenberg 2003). Therefore both models will be discussed in conjunction with collagen and nitrogen values as well as the expected diet in light of other archaeological evidence. The apatite fractionation problem is explicitly discussed (Aranibar *et al.* 2007; Panarello *et al.* 2006-2009; Schwarcz 2006; Tykot *et al.* 2009), with the reduction of its uncertainty margins being one of the major themes of future isotope studies.

Archaeological samples

$\delta^{13}\text{C}_{\text{col}}$, $\delta^{13}\text{C}_{\text{ap}}$ and $\delta^{15}\text{N}$

Twenty-one individuals were sampled for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, though just thirteen gave integral data for collagen and apatite (Table 45). The individuals analysed come from four sites from the Salar de Atacama (Calar, Toconao Oriente, Tulan 54, Tulan 58) and one from the Middle Loa river (Chorrillos), within a time span from the Early Formative to the Late Formative. The samples gave a $\delta^{15}\text{N}$ average of 12.22‰ (range 9.68‰ to 16.28‰); $\delta^{13}\text{C}_{\text{col}}$ average of -15.55‰ (range -9.42‰ to -19.55‰) and a $\delta^{13}\text{C}_{\text{ap}}$ average of -11.18‰ (range -8.03‰ to -15.54‰).

N	SITE	YEARS	SEX	AGE	CONTEXT	Bone	$\delta^{13}ap$	$\delta^{13}Col$	$\delta^{15}N$	$\Delta^{13}C$	C:N
1	Calar	200BC		Ind.	3038	Jawbone	-11.14	no	no	no	
2	Calar	200BC		Ind.	3485	Jawbone	-8.61	-16.11	9.73	7.5	3.38
3	Calar	200BC		Child	3050	Jawbone	-11.71	no	no	no	
4	Calar	200BC		Ind.	3048	Skull	-9.08	-15.34	10.02	6.26	3.42
Average Calar							-10.13	-15.75	9.87	6.88	
5	Chorrillos	820-770BC	M	25	D11 F2 E1 SW	Ribs?	-15.35	-19.55	11.74	4.2	3.23
6	Chorrillos	820-770BC	M	25	C14 F3 E1	Bone	-10.88	-19.53	13.11	8.65	3.51
7	Chorrillos	850-190BC	M	35-40	M9 F2 E1	Ribs	-15.54	-19.17	12.37	3.63	3.22
8	Chorrillos	850-190BC	F	Adult	M6 F3 E1	Ribs	-13.06	-18.21	11.32	5.15	3.27
Average Chorrillos							-13.7	-19.11	12.13	5.40	
9	Toconao Oriente	310AD		Adult	4383	Jawbone	-12.98	no	no	no	
10	Toconao Oriente	10AD		Adult	4331	Skull	-8.33	no	no	no	
11	Toconao Oriente	230AD		Child	4263	Tooth+ ground bone	-11.13	-15.66	13.65	4.53	3.52
12	Toconao Oriente	170BC		Adult	4340	Bone	-8.03	-14.2	12.42	6.17	3.36
13	Toconao Oriente	pretiw.		Adult	4467	Jawbone	-12.2	-16.63	12.49	4.43	3.46
Average Toconao Oriente							-10.53	-15.49	12.85	5.05	
14	Tulan 54	1400-400BC	Ind	Newborn	R2 I3 body 4	Ribs	-9.89	-11.47	16.28	1.58	3.22
15	Tulan 54	1400-400BC	Ind	Newborn	H9 body 17	Bone	no	-9.42	11.46	no	3.26
16	Tulan 54	1400-400BC	Ind	Newborn	I 5 body 8	Ribs	-12.82	-16.12	12.96	3.3	3.18
17	Tulan 54	1400-400BC	Ind	Newborn	G3 body 25	Ribs	-8.25	-16.7	9.68	8.45	3.17
Average Tulan 54							-10.53	-13.42	12.59	4.44	
18	Tulan 58	400- 180BC	Ind	Child	C7 body infant	Ribs	-10.8	no	no	no	
19	Tulan 58	400- 180BC	F	50	tomb 6	Ribs	-10.69	no	no	no	
20	Tulan 58	400- 180BC	Ind	Ind.	tomb 1 ent 1	Ribs	-11.64	-16.06	13.64	4.42	3.56
21	Tulan 58	400- 180BC	Ind	Ind.	Tomb 4	Bone	No	-11.97	13.68	No	3.29
Average Tulan 58							-11.04	-14.01	13.66	4.42	
AV TOTAL							-11.18	-15.55	12.22	5.23	

Table 45. $\delta^{13}Cap$, $\delta^{13}Col$, $\delta^{15}Ncol$ values for 21 individuals sampled (no: no tissue available; values represents the average for each individual).

Within the local baseline, the $\delta^{13}Ccol\text{‰}$ and $\delta^{15}N \text{‰}$ average value for each individual is located between C3 and C4/CAM plants and mainly above the terrestrial protein (Figure 92). $\delta^{13}Cap\text{‰}$ is not plotted.

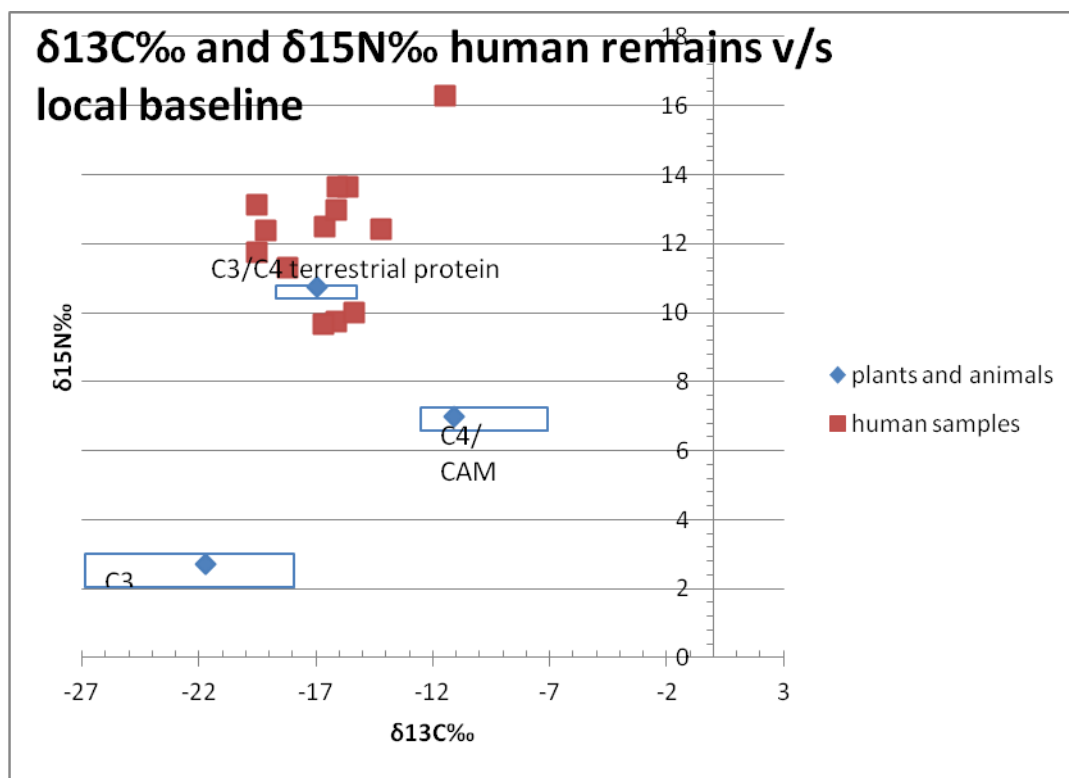


Figure 92. Mean values of δ¹³C and δ¹⁵N for archaeological individuals.

Although it might appear that the high values for δ¹⁵N could represent a marine diet with enriched δ¹³C values in the samples, the lack of correlation between δ¹³Ccol‰ and δ¹⁵N‰ (Figure 93) as well as the high δ¹⁵N values in the local baseline allow us to discard a marine diet. The fact that the δ¹⁵N ‰ values are higher than the fauna tested by López (2010) can indicate both arid stress and the importance of meat consumption (see discussion in page 167). Nevertheless, one individual is an outlier, with a δ¹⁵N of 16 and δ¹³Ccol of -9.89. These values almost certainly represent the “carnivorous” effect of breastfeeding, as they correspond to a newborn.

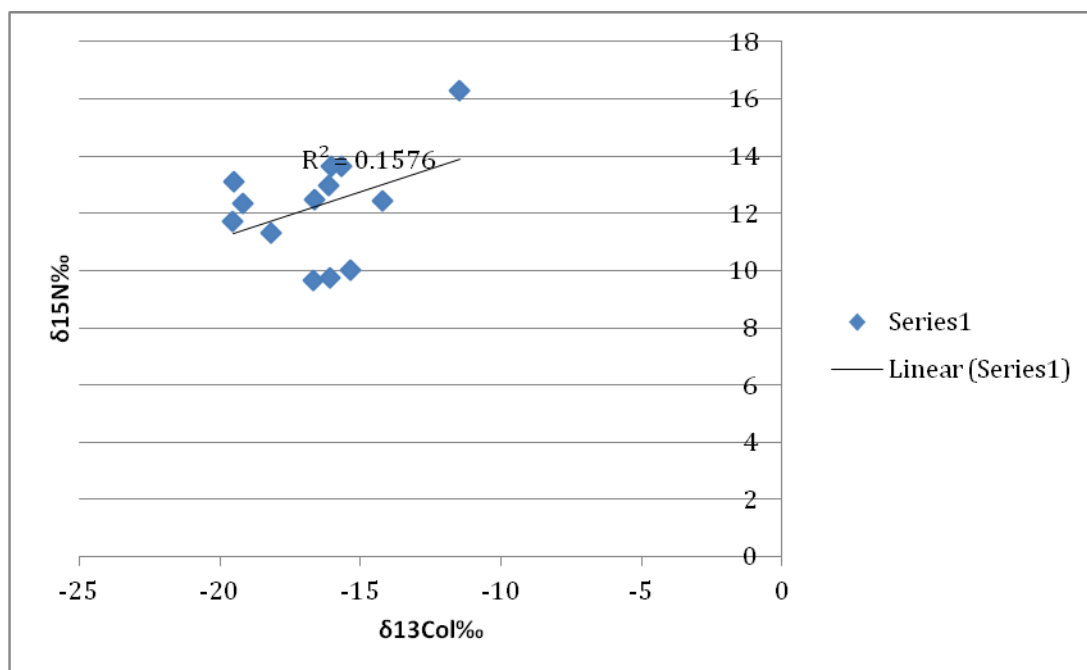


Figure 93. $\delta^{13}\text{C}_{\text{col}}$ correlated to $\delta^{15}\text{N}$.

The modest correlation ($r^2 = 0.39$) between $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{13}\text{C}_{\text{cap}}$ (Figure 94) corroborates the previous relationship and allows us to interpret these values as a product of low C_4 plant consumption and the consumption of terrestrial animals with enriched $\delta^{13}\text{C}$.

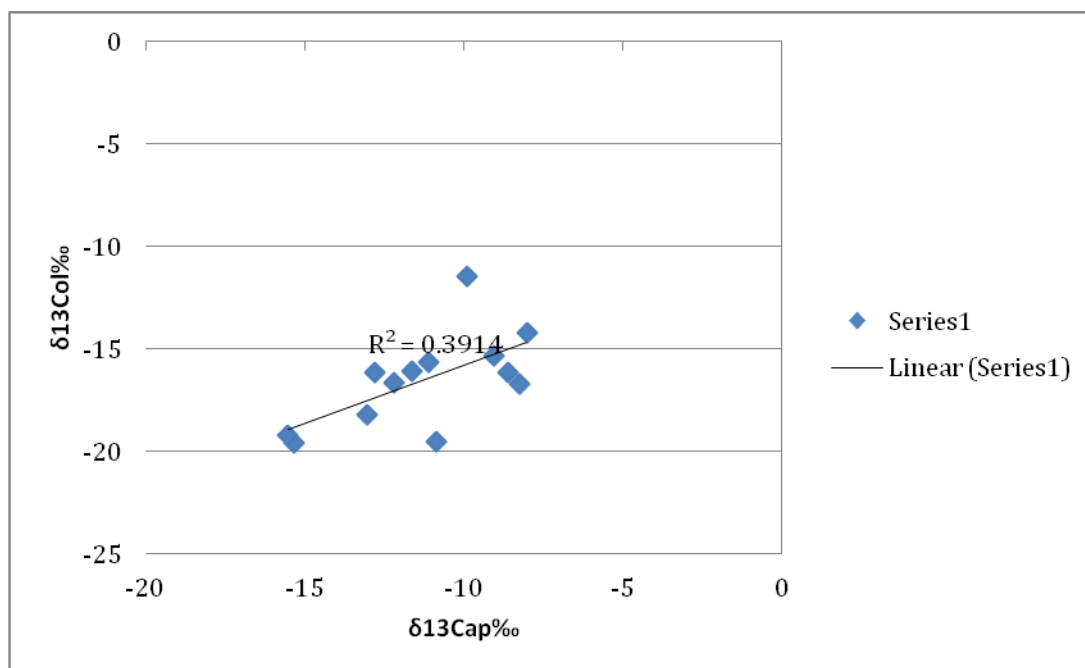


Figure 94. $\delta^{13}\text{C}_{\text{Cap}}$ correlated to $\delta^{13}\text{C}_{\text{Col}}$.

To evaluate when the value of dietary protein is less enriched in the heavier isotope than that of the whole diet, the difference between $\delta^{13}\text{C}_{\text{Cap}}$ and $\delta^{13}\text{C}_{\text{Col}}$ is analysed (Harrison & Katzenberg 2003). There are different models/values to understand this difference (Olivera & Yacobaccio 1999; Panarello *et al.* 2006-2009). In this case I will adhere to the Tykot *et al.* (2009) definition (Table 46) as the main guideline.

C3 v/s C4 components in diet	+12 model	+9.5 model
Mono-isotopic diets	7.0‰	4.5‰
C3 protein/ C4 total	>7.0‰	>4.5‰
C4 total/ C3 protein	<7.0‰	<4.5‰

Table 46. Collagen-apatite spacing models for C3/C4 dietary components. Reproduced from Tykot *et al.* (2009, 161).

When values are 4.5 or 7, mono-isotopic diets are suggested. In those cases where the difference is higher than 4.5 or 7 and the collagen values have not been affected as much as the apatite values, the latter are best explained by direct consumption of C4, and/or Crassulacean acid metabolism (CAM) plants that were not significantly consumed by the main hunted animals (Kelly *et al.* 2006) as well as a more vegetarian trophic level. When values are lower than these ranges, a carnivorous C3 carbohydrate diet with a C4 protein based on marine or terrestrial resources is suggested (Ambrose *et al.* 1997; Harrison &

Katzenberg 2003; Lee-Thorp *et al.* 1989; Panarello *et al.* 2006-2009; Tykot *et al.* 2009), though a C3 protein and carbohydrate diet can also explain these values (Barberena 2002).

Using a model of +9.5 apatite, the data shows that 30.7% (n=3) of the individuals have values around 4.4 ‰ and 46% (n=6) have higher values. This suggests that in the first case, the individuals have an omnivorous monoisotopic diet and in the latter a more vegetarian diet with predominance of direct C4/CAM plants in the whole diet. The other 30.7% (n=3) will be more carnivorous, with a predominance of C4 protein in the diet. This pattern then reflects a major percentage of the individuals relying on direct C4/CAM plant consumption. However, using the +12 model, most of the individuals, 77% (n=10) would have a more carnivorous C4 terrestrial protein diet. The remaining 23% (n=3) present low nitrogen and high ap-col, which coincides with a herbivore diet, though one of them (male, 25 years) is hard to interpret due to the high nitrogen values (Figure 95).

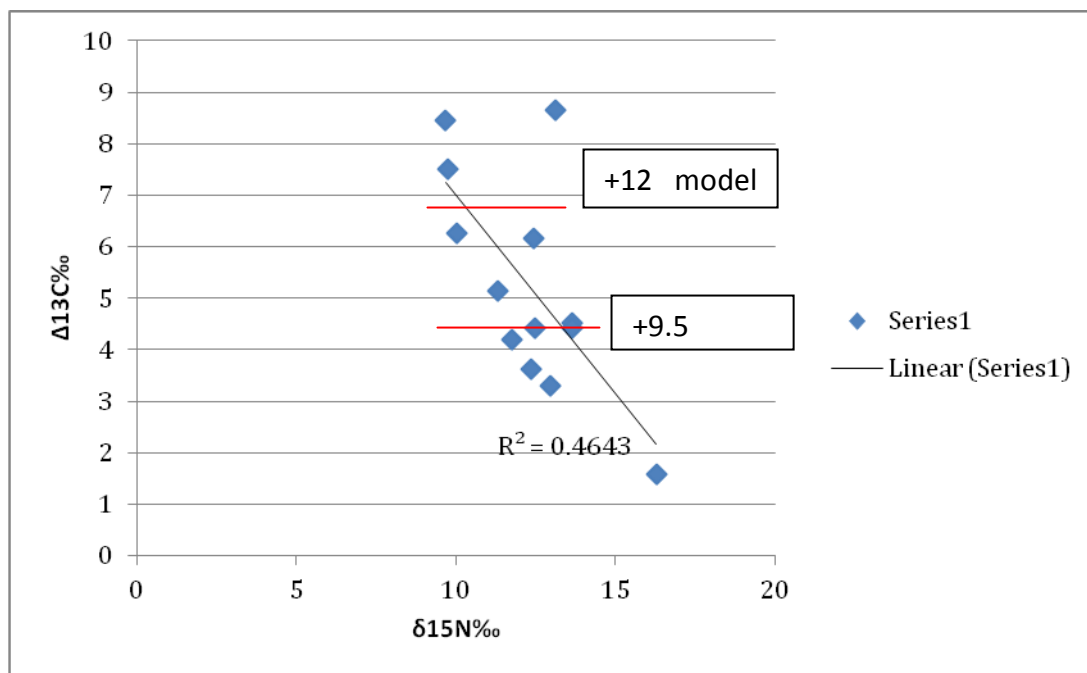


Figure 95. $\delta^{15}\text{N}$ correlated to $\Delta^{13}\text{C}$ col.

With the available evidence, both models are plausible in the area (e.g. consumption of maize or cacti plants or/and consumption of camelids enriched in C4 due to the foraging of *Atriplex*, *Distichlis* or other C4 plants available). In this sense, the remains of camelids are the most ubiquitous evidence in the sites (Barón 1986; Benavente 1982; Llagostera *et al.* 1984; Núñez *et al.* 2005); so they could be an important source of C4 indirect consumption.

As stated above, the enrichment of $\delta^{13}\text{C}$ in the whole diet could either be because of maize consumption or the consumption of cacti (*Trichoceurus* and *Opuntia*), which are present in different proportions within some sites of the period (e.g. Tulan 54), and in the protein, through the consumption of camelids enriched in $\delta^{13}\text{C}$.

The percentage of C4 in the diet can be determined by using the percentage of C4 based on the conversion table above (Table 44) and the consideration of the alternative +9.4 or +12 models (Table 47). Here all the samples with available apatite (n=19) and collagen (n=15) will be discussed.

SITE	$\delta^{13}\text{C}_{\text{col}}$	col +5.1	%c4	$\delta^{13}\text{C}_{\text{ap}}$	ap +9.4	%c4	ap +12	%c4
Calar	No	-	-	-11.14	-20.54	10	-23.14	0
Calar	-16.11	-21.21	0	-8.61	-18.01	30	-20.61	10
Calar	No	-	-	-11.71	-21.11	0	-23.71	0
Calar	-15.34	-20.44	10	-9.08	-18.48	30	-21.08	0
Chorrillos	-19.55	-24.65	0	-15.35	-24.75	0	-27.35	0
Chorrillos	-19.53	-24.63	0	-10.88	-20.28	10	-22.88	0
Chorrillos	-19.17	-24.27	0	-15.54	-24.94	0	-27.54	0
Chorrillos	-18.21	-23.31	0	-13.06	-22.46	0	-25.06	0
Toconao Oriente	No	-	-	-12.98	-22.38	0	-24.98	0
Toconao Oriente	No	-	-	-8.33	-17.73	40	-20.33	10
Toconao Oriente	-15.66	-20.76	10	-11.13	-20.53	10	-23.13	0
Toconao Oriente	-14.2	-19.3	20	-8.03	-17.43	40	-20.03	0
Toconao Oriente	-16.63	-21.73	0	-12.2	-21.6	0	-24.2	0
Tulan 54	-11.47	-16.57	50	-9.89	-19.29	20	-21.89	0
Tulan 54	-9.42	-14.52	70	no	-	-	-	-
Tulan 54	-16.12	-21.22	0	-12.82	-22.22	0	-24.82	0
Tulan 54	-16.7	-21.8	0	-8.25	-17.65	40	-20.25	10
Tulan 58	No	-	-	-10.8	-20.2	10	-22.8	0
Tulan 58	No	-	-	-10.69	-20.09	10	-22.69	0
Tulan 58	-16.06	-21.16	0	-11.64	-21.04	0	-23.64	0
Tulan 58	-11.97	-17.07	50	no	-	-	-	-

Table 47. % of C4 plants for each individual using different fractionation models.

When using a +9.4 apatite model, 42% (8) individuals present a low-medium intake of C4 (10%-40%) (Figure 96), whilst with the +12 model, just 15% (3) of the individuals present C4/CAM consumption in the whole diet (10%) (Figure 97).

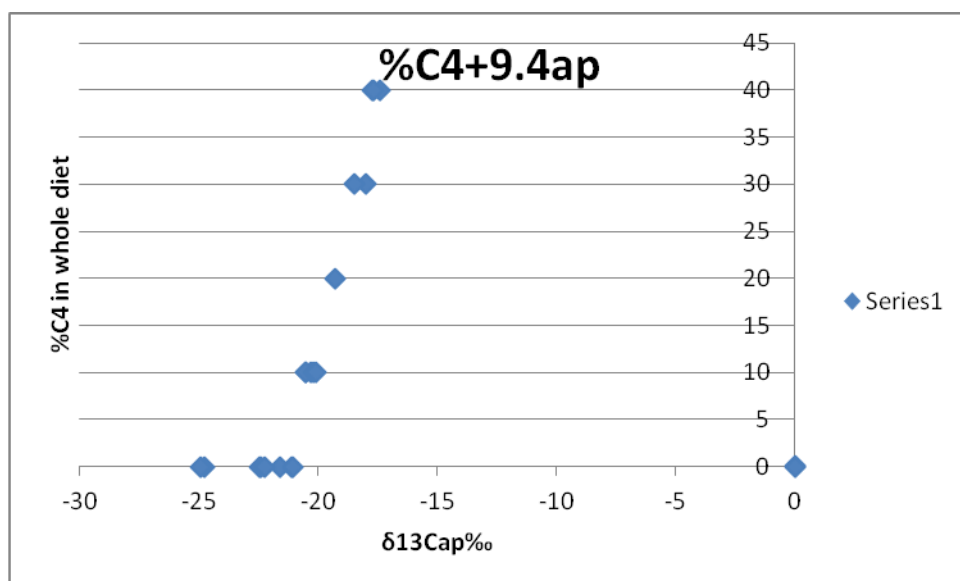


Figure 96. +9.4 model for apatite fractionation.

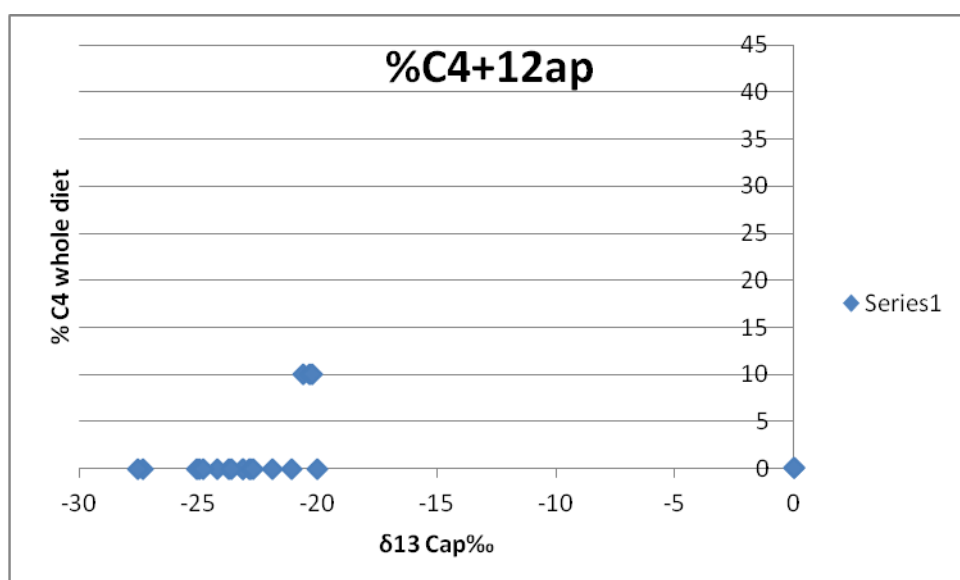


Figure 97. +12 model for apatite fractionation.

When assessing the percentage of C4 in the protein, 40% (n=6, see table 47) of the individuals show the presence of C4 (10-70%) (Figure 98). This might be due to the C4 enriched diet of the camelids, though those individuals with a percentage of C4 above 50% need to be understood within their own context, as two of these individuals are newborns (Tulan 54) and the other is undetermined (Tulan 58). Hence, these values could be reflecting the breastfeeding carnivorous effect.

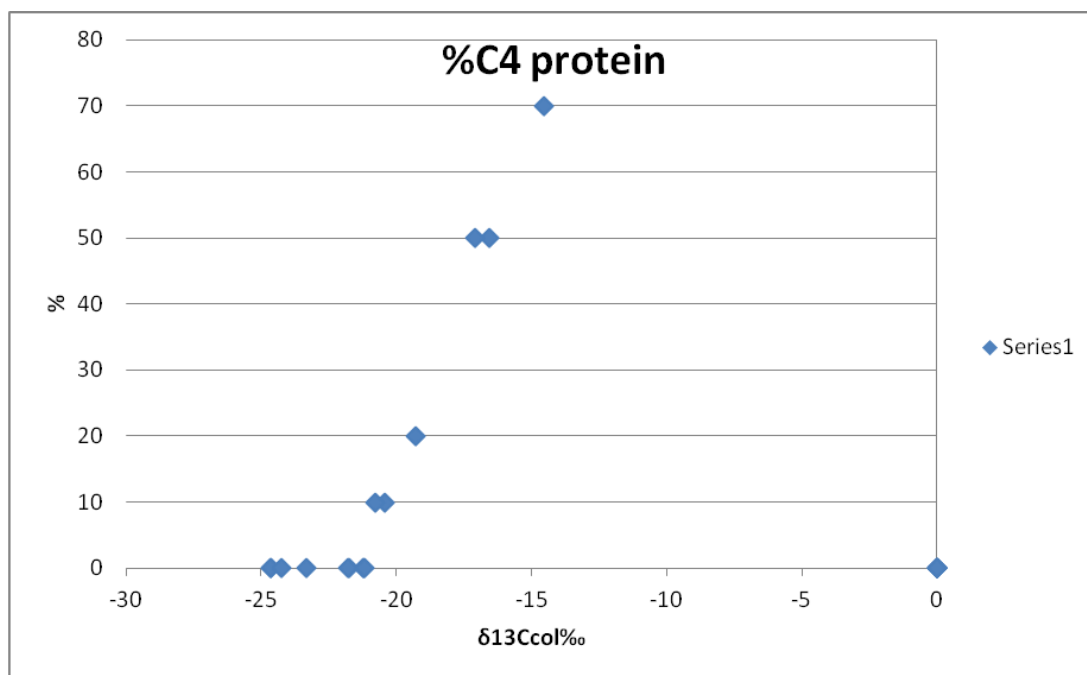


Figure 98. +5.1 model for collagen fractionation.

δ 87Sr/86Sr and δ18O

87Sr/86Sr

Two sites were analysed for $^{87}\text{Sr}/^{86}\text{Sr}$ isotopes, namely Chorrillos and Tulan 58. Of ten samples analysed, two were rodent bones and eight human teeth (Table 48).

<i>SITE</i>	<i>AREA</i>	<i>PERIOD</i>	<i>YEARS</i>	<i>CONTEXT</i>	<i>SEX</i>	<i>AGE</i>	<i>87Sr/86Sr</i>
<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>L9 F2 E1</i>	<i>M</i>	<i>25-30</i>	<i>0.70739</i>
<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>L9 F2 E1</i>	<i>M</i>	<i>25-30</i>	<i>0.70744</i>
<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>C14 F2 E1</i>	<i>F</i>	<i>23-33</i>	<i>0.70736</i>
<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>H 15 F1 E1</i>	<i>F</i>	<i>20-25</i>	<i>0.70765</i>
<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>L12 F2 E1</i>	<i>?</i>	<i>Indeterminate</i>	<i>0.70751</i>
<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>C18 F1 E1</i>	<i>?</i>	<i>Indeterminate</i>	<i>0.70716</i>
<i>Tulan 58</i>	<i>Salar</i>	<i>Late Formative</i>	<i>400-180BC</i>	<i>C7</i>	<i>?</i>	<i>Adult</i>	<i>0.71087</i>
<i>Tulan 58</i>	<i>Salar</i>	<i>Late Formative</i>	<i>400-180BC</i>	<i>E1 tomb 1</i>	<i>?</i>	<i>Adult</i>	<i>0.70759</i>
<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>P17 F4SE</i>		<i>Rodents</i>	<i>0.70736</i>
<i>Chorrillos</i>	<i>LOA</i>	<i>Early Formative</i>	<i>850-190BC</i>	<i>E12NW rasgo2</i>		<i>Rodents</i>	<i>0.7074</i>

Table 48. Archaeological values of 87Sr/86Sr isotopes.

The two rodents from Chorrillos gave values of 0.70736 and 0.70740. There is very little difference between these results and they are the same or only slightly different from San Pedro faunal remains, which range from 0.7074 to 0.7079, with a mean of 0.7076 (Knudson 2008).

Looking at table 48, the group of data is consistent with the area in which they were found, though one individual's Sr values suggest that they are not from this area but somewhere more radiogenic (Tulan 58 C7). Based on previous research, the value of this individual is nearer the values of the modern and archaeological fauna recorded in the Tiwanaku area, in the highlands of Bolivia (Knudson 2008). This latter individual did not have any offerings or cultural remains diagnostic of a foreign area. As the tooth is formed during the early stages of life, it could be that this individual arrived in the Atacama area any time from being a young juvenile till death, though is not possible to confirm when they moved without bone analyses.

$\delta^{18}\text{O}$

$\delta^{18}\text{O}$ isotopes have been criticised for their potential to establish residential mobility (Knudson 2009). However, samples (Table 49) provide a preliminary indication that Chorrillos has a range between $\delta^{18}\text{O}$ -5‰ and -7‰ with a mean of -6.29‰.

SITE	YEARS	SEX	AGE	CONTEXT	Bone	$\delta^{18}\text{O}$
Calar	200BC		Ind	3038	Jawbone	-5.11
Calar	200BC		Ind	3485	Jawbone	-3.14
Calar	200BC		Child	3050	Jawbone	-4.55
Calar	200BC		Ind	3048	Skull	-6.35
Average Calar						-4.78
Chorrillos	820-770BC	M	25	D11 F2 E1 SW	Ribs?	-7.79
Chorrillos	820-770BC	M	25	C14 F3 E1	Bone	-6.83
Chorrillos	850-190BC	M	35-40	M9 F2 E1	Ribs	-5.28
Chorrillos	850-190BC	F	Adult	M6 F3 E1	Ribs	-5.28
Average Chorrillos						-6.29
Toconao Oriente	310AD		Adult	4383	Jawbone	-6.93
Toconao Oriente	10AD		Adult	4331	Skull	-5.13
Toconao Oriente	230AD		Child	4263	Tooth + ground bone	-4.77
Toconao Oriente	170BC		Adult	4340	Bone	-3.57
Toconao Oriente	preiw.		Adult	4467	Jawbone	-4.29
Average Toconao Oriente						-4.93
Tulan 54	1400-400BC	Ind	Neonate	R2 I3 body 4	Ribs	-3.61
Tulan 54	1400-400BC	Ind	Neonate	I 5 body 8	Ribs	-4.65
Tulan 54	1400-400BC	Ind	Neonate	G3 body 25	Ribs	-0.93
Average Tulan 54						-3.06
Tulan 58	400-180BC	Ind	Child	C7 body infant	Ribs	-4.36
Tulan 58	400-180BC	F	50	tomb 6	Ribs	-4.22
Tulan 58	400-180BC	Ind	Ind.	tomb 1 ent 1	Ribs	-5.8
Average Tulan 58						-4.79

Table 49. $\delta^{18}\text{O}$ values for archaeological samples.

These values are lower than most inland sites (Toconao Oriente: -4.93, Calar: -4.78 Tulan 54: -3.06, and Tulan 58: -4.79) and hence it is problematic to interpret them due to the

environmental premise of a decrease in $\delta^{18}\text{O}$ in precipitation or meteoric water ($\delta^{18}\text{O}_{\text{mw}}$) with increasing altitude and increasing distance from the coast (Knudson 2009). Nevertheless Santana (pers. comm. 2013) states that for sites near the coast of northern Chile, $\delta^{18}\text{O}$ values are very negative as well, and this might be due to the consumption of underground waters coming directly from the highlands and therefore without the evaporation rates that increase their values in lower altitudes. In Calama, where Chorrillos cemetery is settled, the waters of the Loa River are very salty due to they have already joined to the Salado River and therefore, most probably is that local populations searched for other sources of sweet water. Also some individuals from Tulan 58, 54, Toconao and Calar are within the Chorrillos range. Regarding newborns from Tulan 54 (aged up to twelve months) and the enrichment that might happen due to the mother's breast-milk, only one individual showed a higher value than the rest. It might be that not all of these babies were breastfed or that the two non-enriched samples had already started to eat solids.

High variability in $\delta^{18}\text{O}$ isotopes within sites has previously been documented by Knudson (2009) and Knudson & Torres-Rouff (2009), who complement these analyses with $^{87}\text{Sr}/^{86}\text{Sr}$, concluding that $\delta^{18}\text{O}$ should not be taken as a reliable indicator of residentiality due to the movement of waters within the Andes.

Hence oxygen and $^{87}\text{Sr}/^{86}\text{Sr}$ have not shown patterns of mobility, in part due to the small sampling, although at least in Tulan 58, one individual could have lived in the highlands during his infancy.

Regarding $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values to assess differences based on different foodways, the small size of the samples does not allow confident interpretations, though Chorrillos presents less enriched $\delta^{13}\text{C}_{\text{col}}$ and $\delta^{13}\text{C}_{\text{cap}}$ values (Figure 99). Of the sites sampled, Chorrillos is the only site located in the Loa Medio, though this area has similar vegetation to the inner oases and therefore vegetation should not affect the values either of direct or indirect $\delta^{13}\text{C}$ plant consumption. Hence the differences might be reflecting diet and food choices rather than ecological variables, unless the same resources (camelids) were eating higher amounts of C3 plants in comparison to the inner sites and therefore altering the protein diet signal for individuals eating camelid meat at Chorrillos. These values questions previous assumptions

about a moderate consume of marine resources based purely in δN^{15} (Gonzalez and Westfall 2006).

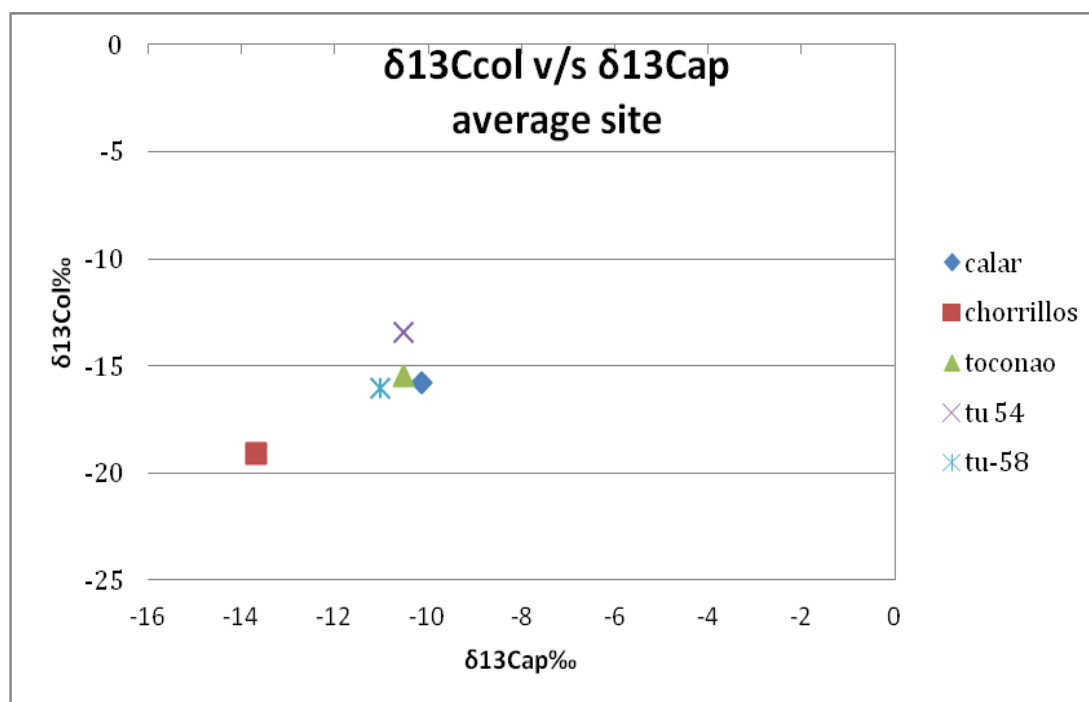


Figure 99. Mean values of $\delta^{13}C$ and $\delta^{15}N$ per site.

Regarding the whole diet, this seems more variable within Chorrillos site, having a range from $\delta^{13}C_{Cap}$ from -10 to -15 (mean -13), so at least one individual is having a small amount of C4 plants (Figure 100), which could be either from some C4 species of the Chenopodiaceae family, as macro-remains support (Belmar & Quiroz 2005), from CAM, as one *Opuntia* phytolith shows, or from maize, which has not been found in the site; though at this point it is not possible to discriminate among any of them. The $\delta^{15}N$ mean of 12.1 is not indicative of diet due to arid conditions.

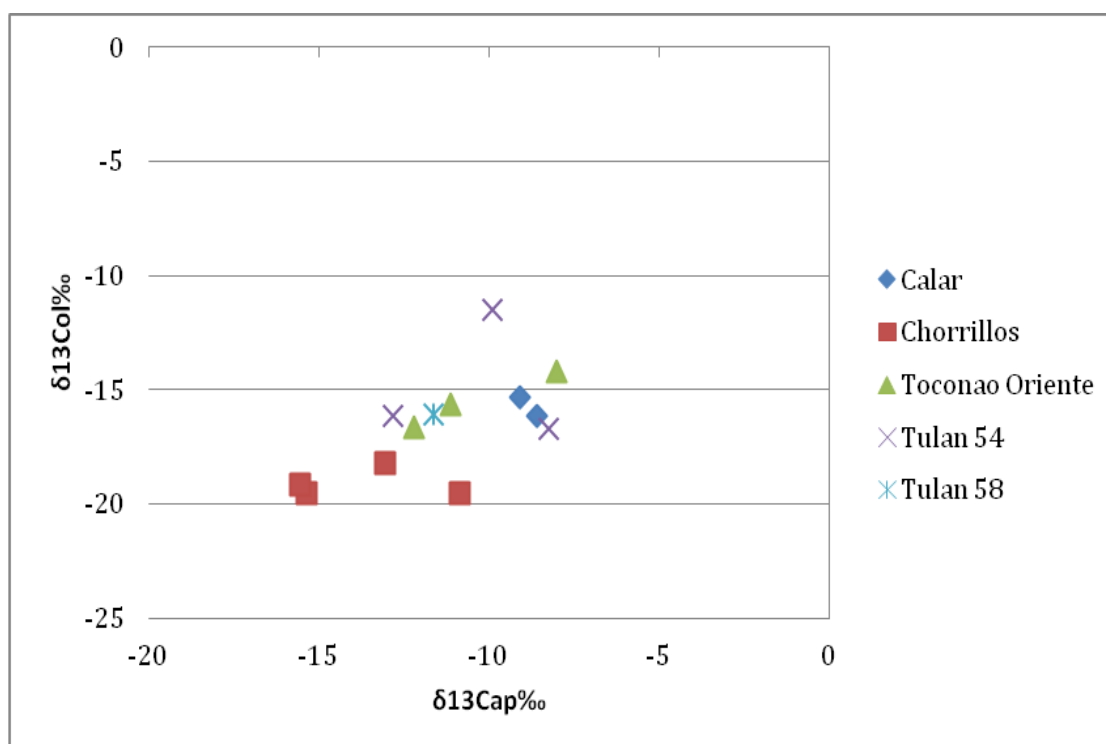


Figure 100. Individual values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$.

Summary

The microfossils found allowed us for the first time to complement archaeobotanical macro-remains and give new data about plants and their association with tool use. Microfossils were identified according to their morphological characteristics. Some of them could not be identified, whilst the others ranged from upper levels such as class (dicot-monocot) to genus/species, but broader categories (tuber type) were also established. In this identification, similarity in starch grains made taxonomical identification difficult. I found several variants overlaps between species and therefore all of my identifications were made under cf. (compare with). Also I use a conservative approach when recognising different microfossils, especially when dealing with domestic plants such as maize or *Chenopodium quinoa*. *Capsicum* and Cucurbitaceae should also be taken cautiously until more reference collections and samplings on artefacts are done. I acknowledged the resemblance between maize and *Prosopis*. Some previous authors have mentioned variants which might be useful to distinguish them, hence recognising their similarity; though in my reference collection there is significant overlap, especially with the regular types of starch grains (Table 36).

The triangulation of the different microfossils found in artefacts does not allow me to resolve this and other uncertainties. I have only two cases in which taxa are present as different microfossils (Cyperaceae and *Prosopis*), not within the same artefact but sometimes within the same site. Also the coincidence between macro-remains and micro-remains was evaluated site by site to assess potential contamination of the artefacts within the matrix rather than their attachment due to cultural manipulation of the plant with the tool. Half of the cases did not present coincidence between the macro-remains and microfossils in the sites and the other half did not have clear contexts to assess contact between macro and micro-remains in the matrix (Table 37). Nevertheless, as taphonomic processes are still not well understood and because numerous variables biased our record, it is hard to propose a 100% correlation between microfossils and tools. However, in spite of this potential contamination within the matrix, I have discussed my reasons for identifying those microfossils which I think were caused by human agency and therefore represent the plants used in the sites and periods under study.

Microfossils were divided into non-cultural versus cultural origin (Table 41) depending on their abundance in the sites, ecology and taphonomic variables (dispersion, deposition, conservation etc). Most of the species considered as cultural do not grow in the sites and therefore were probably carried to the site by people during the habitation of the site. Even if the presence of cultural microfossils on artefacts is low, the confidence of my results relies on the size of the original sample and the repetition of microfossils between tools from different sites (Figure 80, 81), from different museum premises (Figure 74) as well with previous archaeobotanical samples (Table 21). This evidence should be constantly re-evaluated in the light of new studies and references of microfossils in the area.

My results show some general patterns. Wild plants (Cyperaceae, *Prosopis* and *Opuntia*) predominate over potential crops (Figure 89). In this sense, the lack of some expected microfossils on hoes (crosses, rondels, bilobes) is important evidence against previous arguments that these hoes were used for maize agriculture. The presence of diverse microfossils on the hoes leads me to propose a multipurpose function for this tool (Figure 80). For grinding tools, I could not correlate the processing of specific resources with types of morphology. Late Archaic conical mortars present resources such as Cyperaceae and

Opuntia. Formative grinding tools, especially from the ravines, keep showing these resources but also present some “new” resources such as *Prosopis* and tubers (Figure 81), which are more evident in the oases (Figure 83). However, when considering this difference, we should keep in mind the smaller size and differential taphonomic conditions of the Late Archaic sample. Apart from this pattern, I did not find clear differences between sites. Some of them showed more presence and diversity of taxa, though since the samples are uneven between sites, I cannot assume these trends as merely cultural aspects of the data.

Isotope analyses was collected and analysed to complement and help evaluate the archaeobotanical data, supporting both its strength and its ambiguity (Table 45). Thus it showed that there is not a generalised nor a predominant C4 diet; though its resolution does not allow us to determine C3 plants’ diversity and whether C4 values could be related to CAM or maize, both of which are present in macro as well as micro remains. Also the size of the sample represents a small number of individuals per site, though with consistent patterns, except for the newborns, whose values are random *per se*. The available reference baseline for camelids should be expanded in order to determine with more precision whether high values in collagen are related to indirect consumption of C4. In this sense, the arid conditions of the area do not allow us to rely on Nitrogen as an indicator of marine diet.

In the next section I will discuss what my results mean in light of the research questions and within the broader cultural context.

CHAPTER IX. DISCUSSION New perspectives about the role of plant production in the Formative changes of the western slope of the Puna de Atacama

Introduction

In this chapter, I use the analyses presented previously to address the broader research questions of this thesis and develop a revised interpretation for the role of plant production within the Formative period of the Atacama. In the introduction and the review of theories relating to the origin and spread of agriculture, I questioned current models in Atacama, which presume some elements of the Formative concept, such as food production of domesticated plants like maize, as having a primary role. I also questioned the use of pressure models in the explanations of changes, proposing that risk management strategies and the middle ground territory between food procurers and agriculturalists should be further explored to gain a better understanding of the processes and reasons under which Early Formative societies would have changed their way of living.

Therefore, the analytical methods that I selected and developed have been designed to break away from a simplistic assumption that an occasional maize cob implies agriculture or horticulture, and that this is the only avenue for complexity. The resulting evidence has shown that these methods are capable of identifying a diversity of practices relating to cultivation, processing and consumption for a wide spectrum of plants.

In this chapter I evaluate this evidence to assess what it can tell us about these practices across the Atacama region, and the degree to which this can contribute to a more nuanced model for the social and economic changes that characterise this particular example of 'The Formative'. This new evidence for more varied food production and consumption is discussed with reference to my first objective, which provides a new model for the local history of Atacama, but also to my second objective, in which I take a wider focus regarding systems of human, plant and animal interaction. Then, within my third objective, methodological issues such as taphonomic problems and contributions to the studies of

microfossils will be discussed. Finally, at the end of this chapter, I present some suggestions as to how this research could be more thoroughly evaluated and improved in the future.

IX.1 Answering the research questions

Recalling the introduction, my research questions are:

1. What plants were dominant and how were they managed by the Formative peoples living in the Atacama Region? Why and how do these patterns vary through time and space?
2. Why do lithic hoes appear during the Early Formative? Are they related to farming practices?
3. Why were new grinding technologies adopted during the Formative period? Are they related to the processing of new resources (crops)?
4. Why were previous occupations in the ravines abandoned and new permanent settlements in the oases established during the Formative period? Is this related to the onset of agriculture?
5. Is it possible to identify whether these changes are autochthonous or if they relate to new populations moving into the area?

1. What plants were dominant and how were they managed by the Formative peoples living in the Atacama Region? Why and how do these patterns vary through time and space?

As I showed with the microfossil results and corroborating previous archaeobotanical research (McRostie 2007; Núñez *et al.* 2009; Vidal 2007), wild plants were predominant in the Late Archaic as well as the Formative period. Similar resources such as Cyperaceae, Cactaceae and cf. *Hoffmannseggia* (tuber) are present in both periods; however, there is a diversification and a change in the resources by the Formative period with the introduction of *Prosopis*, other tuber types, *Geoffroea decorticans* and some scarce crops (Figure 101).

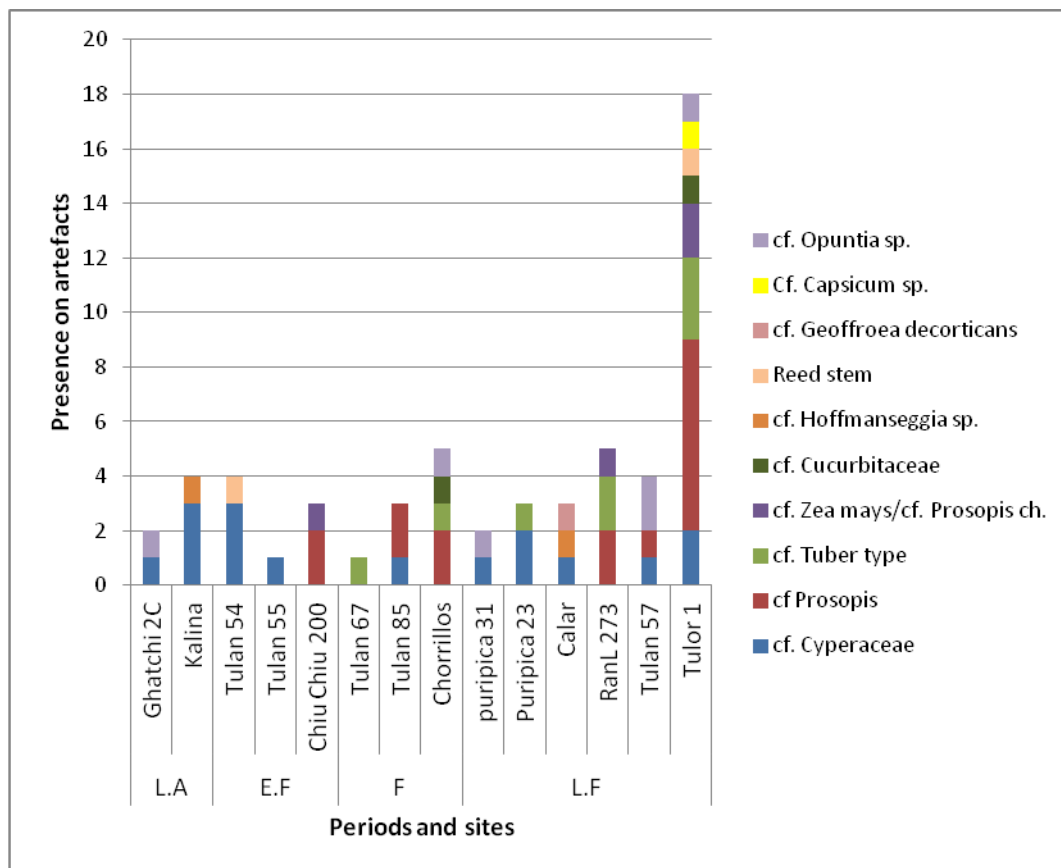


Figure 101. Presence of taxa on artefacts by sites and periods. L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).

This continuity through time might be reflecting food choices and risk-spreading strategies (Minnis 1992). However, diversification of plants would also have ensured social reproduction within major structural changes. Risk strategies allow the examination of the context under which people could explore new avenues for subsistence. In this transition, the new elements could be seen as a risk minimiser, allowing an initial diversification. Then, through a co-evolutionary or intensification process, it will become an efficient source of food (McClure *et al.* 2006).

During the Late Archaic period, resources such as Cyperaceae, tubers and *Opuntia* and others that are less known and underexploited nowadays could have been an important source of calories for hunter/gatherers and initial herders of the Atacama (Munizaga *et al.* 1958), and even afterwards, during the Formative period, when more resources were circulating, these wild plants were still relevant in their diet, being one of the five most ubiquitous plants (Figure 102).

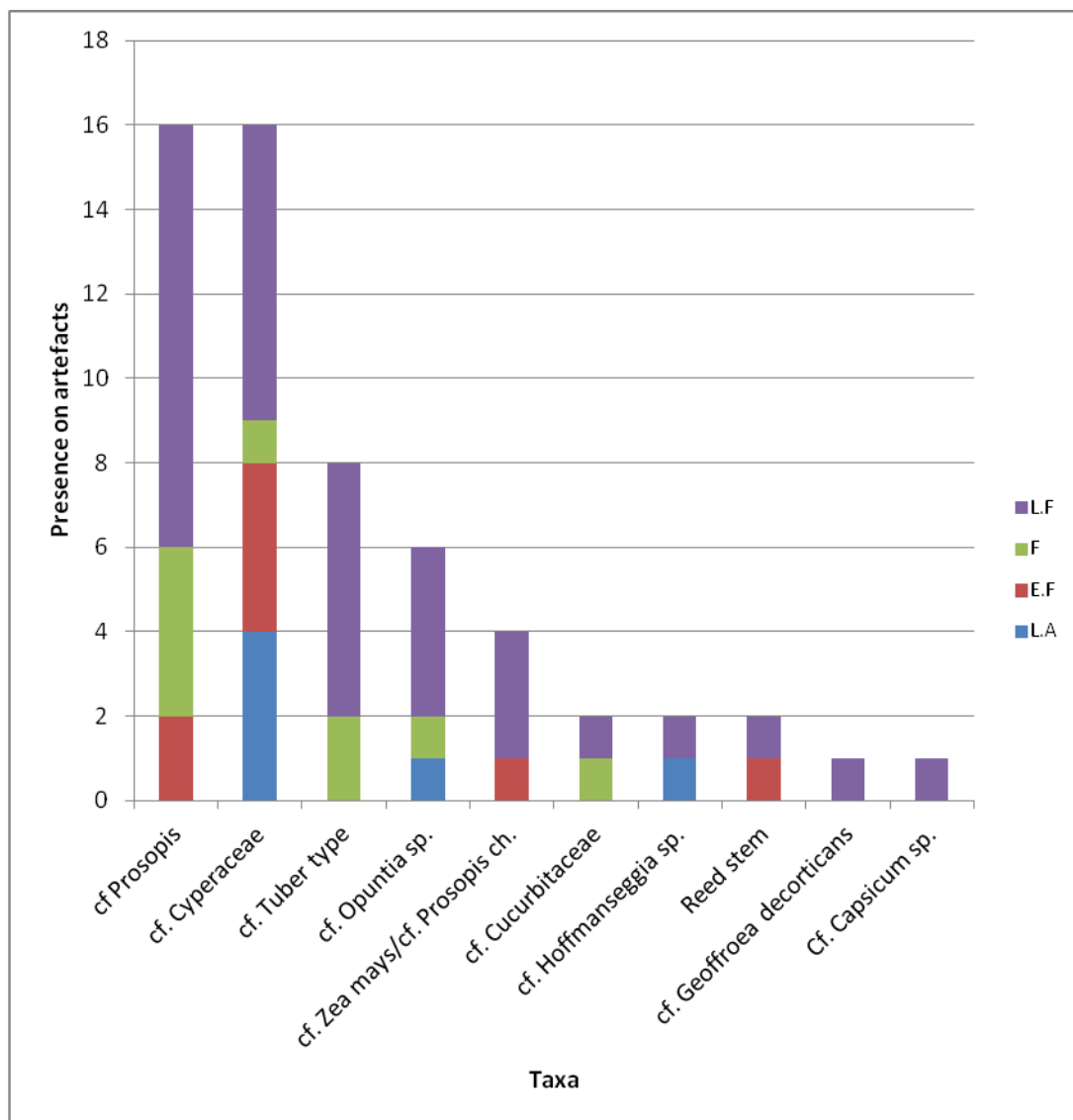


Figure 102. Presence of microfossil taxa by periods. L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).

Cyperaceae and *Opuntia* macro-remains have been reported as edible species in local ethnobotany (Villagrán *et al.* 1998b) and archaeologically in previous local Archaic and Formative sites (Druss 1976; Holden 1991; McRostie 2007; Núñez *et al.* 2009; Sinclair 1985; Vidal 2007). Also, their processing and consumption by local populations of the Formative period has been confirmed by the analyses of guts and coprolites in Tulan 54 and 58 (Holden 1991). In the worldwide archaeological context, Cyperaceae or reeds and Cactaceae have been reported as relevant in the diet (Cane 1989; Danielson & Reinhard 1998; Flannery 1968; Holden 1991; Messner 2008; Schmeda-Hirschmann *et al.* 1999; Wollstonecroft 2007; 2009; Wollstonecroft *et al.* 2008; Wollstonecroft & Erkal 2003; Wollstonecroft *et al.* 2011).

The constant presence of these resources allows exploration of different levels and categories for their management in the area and periods under study.

Regarding Cyperaceae, Holden states that “On excavating samples from the stream or waterhole sides in Chile today, the tubers are generally small and fibrous and the outer layers are commonly dark brown to black in colour. Only in favourable places such as in the central parts of the streams or very edge of the waterholes, where grazing has been restricted and crowding of the plants is not evident, do larger more succulent and paler coloured underground organs prevail...the pale colour of much of the archaeological material from Tulan 54 suggests that these resources were also being managed. This would most probably have been done by repeated thinning out of stands of plants as the underground organs were taken for food and restricting grazing. In this way, a more favourable environment for the growth of a better quality of resource would be created and larger and more palatable rhizomes would result” (Holden 1991, 326). Another species from the Cyperaceae family (the Sea Clubrush) has been documented as tightly linked to human habitats, and is of significance in the archaeobotany of the Near East “because the nutlets and sometimes the tubers have been recovered in notably large numbers from Epipalaeolithic and Early Neolithic archaeological sites in Anatolia, the Levant and Mesopotamia” (Wollstonecroft *et al.* 2011, 459). Wollstonecroft (2007) gives several examples worldwide of *Scirpus* management, concluding that “if people were to intensively harvest tubers, they would learn to identify from different variables those plants with high below-ground productivity” (Wollstonecroft 2007, 223). She also stresses that rotation will be necessary in order to “prevent overly fragmenting the clones, to allow mother plants to re-establish themselves and to permit recently newly-severed, isolated clones to consolidate and enlarge their underground networks. Hence, seasonal harvesting of the tubers appears to be the most productive collecting strategy, but opportunistic harvesting can be done at other times of the year” (Wollstonecroft 2007, 224). However, contrary to what Holden (1991) described, Wollstonecroft states that grazing encourages the growth of these underground organs and that those more mature tubers, rather than younger ones, would be richer in carbohydrates and starch grains. But her work was based exclusively on tubers, while Holden refers to tubers and rhizomes without distinction: thus, it could be that

some differences could be found between both underground organs and different species. Hather (1994) suggests that wild patches of these plants may not have been intensively managed or cultivated due to their rhizomatous habitat, and hence the increased labour input would occur mainly in the harvesting and post-harvesting stages (Wollstonecroft 2007, 137). In the Titicaca, Whitehead proposes that “One example of a quasi-domesticate, if we accept this line of thinking, is *Schenoplectus totora* which occupies most of the broad littoral zone in the shallow Winamara basin” (Whitehead 2006, 260). Thus, for Atacama, more botanical and ethnoarchaeological work should be done in order to have a more precise understanding of the management and levels of domestication if any, for these plants.

Within tuber types,¹⁵ there are several wild dicots that have edible underground organs in the area (*Ombrophytum subterraneum*, *Junellia digitata*, *Nototriche estipulate*, *Tiquilia atacamensis*, *Hoffmannseggia* sp.) (Villagrán *et al.* 1998a; Villagrán *et al.* 1998b), and although there is currently an inadequate knowledge of wild tuberizing *Solanum* species, the domesticated varieties should be *Solanum tuberosum* spp. andigena (J. Kalazich pers. comm. 2013). In the Northwestern Argentina Puna, there are around seventeen *Solanum* species that produce tubers (Babot 2004, 198). In the Bolivian Highlands, studies have shown that some wild tubers can be more resistant to frost and drought and have higher kilocalories/gram than domesticated ones (Coleman 2008, cited in Pintar 2008). Hence it could be that the tuber type starches correspond to one or multiple families and therefore the imprecise taxonomy of the starches only allows me to discuss potential avenues of management for possible plant producers of these starches. There is no macro-remain evidence of tubers during the period and area under study, so their presence was not recognised till this microfossil research. Only one starch grain was found in the Formative site Tulan 55 (McRostie 2007). This lack of correlation between macro and micro remains of tubers has also been reported in the Northwestern Argentina Puna (Babot 2004) and is part

¹⁵ “The term roots and tuber is a convenient handle use to describe any swollen vegetative storage organ – root, rhizome, corm, tuber, stolon, etc.” (Hather 1994, 719).

of the intrinsic bias that underground organs have in preservation and visibility in archaeological contexts (Hather 1994; Logan 2006; Ugent *et al.* 1982b; Whitehead 2006).

However, starch grains allow us to see that tubers are present in different sites by the Formative period (Figure 103). Therefore, their presence might reflect some level of management if in fact they were being cultivated and were not exclusively imported from the highlands or southern latitudes, as some ethnographies and chronicles state (see CH.V, ethnographic and ethnohistorical data).

During the Late Archaic, the tuber-type starch identified preliminarily as *Hoffmannseggia* shows continuity through the sequence and it has also been reported in QS3, a Late Archaic site of the North-western Argentina Puna (Rodríguez 1999b). Villagran and colleagues report that some tubers of *Hoffmannseggia doellii* are better than others and are extracted from certain places (Villagrán *et al.* 1998b, 46) and hence probably these could have been more intensively managed. Unfortunately in Atacama there is not much information regarding management of tubers or roots, but Pardo (2007) describes for the northern highlands of Arica that people usually eat *Ombrophytum subterraneum* where they find it, burying the rinds afterwards so they will grow the next year and can be found in the same place.

Roots and tubers have the advantage that in most cases they can be stimulated to grow by harvesting as well as planting because they reproduce vegetatively as well as sexually (Wollstonecroft 2007, 135). Vegetative propagation for tuber plants is known to increase plant growth and production (Piperno & Pearsall 1998a; Sauer 1952). However, in the case of potatoes, this statement does not fully apply, as a sexual seed can produce as vigorous a plant as one produced by vegetative reproduction (J. Kalazich pers. comm. 2013). Nevertheless, the rate of reproduction of desired traits (e.g. larger fruits, the loss of chemical defences against herbivores, or changes in sugars and starches) by replanting root fragments respond fairly quickly to deliberate human selection (Harlan 1975; Zeder 2006). Larger tubers and changes in starch composition according to the methods of preparation employed were methodically selected during early management of tubers (Piperno 2006a). In fact, recent studies have made it possible to detect domestication-induced morphological changes at a microfossil level in root and other crop plants (Piperno 2006a; Piperno & Pearsall 1998a). For instance, starch grains from wild yam species are distinct in morphology

as compared with domestic varieties. As a rule, wild forms are also highly variable within a single tuber, whereas domesticated species have a single morphological type of starch, which may be a result of human selection (Zeder 2006, 108). Hawkes (1989) describes three stages of domestication for tubers similar to seed crops: first by colonisation of weedy plants close to the sites of hunter-gatherers, then by a regular harvesting of roots and tubers and thirdly when planting and harvesting took place (Hawkes 1989, 481). Grun (1990, 42), referring to *Solanum* varieties, states that “It does seem possible that early man gathered tubers of wild species of the brevicaulis complex, and these became the later basis for field plantings of *S. phureja* and *S. stenotomum* selected during domestication. *Solanum stenotomum* has adaptation to field conditions at high altitudes and tuber dormancy which allows for storage over winter”.

Whether the Formative tuber types are domesticated varieties of the Highland Complex, wild varieties of *Solanum* or any other tuber types available in the area should be confirmed with much more interdisciplinary work between botanists and archaeologists. Nevertheless the early use of tubers is in agreement with current research about domesticates in the Andes (e.g. Babot 2004; Korstanje 2005; Pearsall 1992; Piperno *et al.* 2007; Santoro & Chacama 1982). In Northwestern Argentina, tubers and roots predominate around the Middle Holocene (Babot 2004; Babot 2006; Pintar 2008). “Many authors have argued that tubers and pseudo-cereals were among the first products to be domesticated, while maize would not have acquired preponderance until agriculture was fully established perhaps towards the end of the Early Formative period (ca. 600AD)” (Calo & Cortes 2009, 200). Domestication of diverse Andean tubers could be underway by 5800BC and an early presence of tubers has been reported in Northwestern Argentina, the Bolivian Highlands and Huaynuma in the southern highlands of Peru (Babot 2004; Langlie *et al.* 2011; Pearsall 2008; Perry *et al.* 2006). Pearsall (1989) proposed that *Lepidium* roots were under a domestication process around 3000BC and 1200BC in the highlands of Peru in Panalauca cave when tubers take “an increasingly important role in diet” (Pearsall 1989, 325).

The management of *Opuntia* through different periods is difficult to interpret, as there is no information in local ethnobotanical texts. However, the recurrent presence of different cactaceae genera through sites of different periods of the Atacama requires consideration

of some sort of food production rather than mere food procurement. Flannery (1968) reports succulent cactis as one of the three important plants for incipient cultivators in early Mesoamerica (8000-2000BC). *Opuntia* and *Echinopsis* seeds have also been reported in Panaulauca cave, confirming the relevance of these species in the pre-ceramic and ceramic contexts of the Peruvian Highlands (Pearsall 1989). In Mexico, ethnobotanical studies of cactus species have shown that people collect fruits selectively, choosing individual species for flavour properties, thinner pericarp, fewer spines and larger size. People commonly protect naturally established individuals, and other activities such as pruning, fertilising and cultivation in the home garden, whether by protected seedlings, sowing or vegetative reproduction, are performed (Casas *et al.* 1997, 287). Currently in Atacama, indigenous descendants believe that it is beneficial to have cactus in their houses because they repel bad energies (O. Mora pers. comm. 2013).

At this point, it is not possible to model the role that these three resources (tubers, cacti and *Scirpus*) had in diet and subsistence during the periods when they were present (Figure 103).

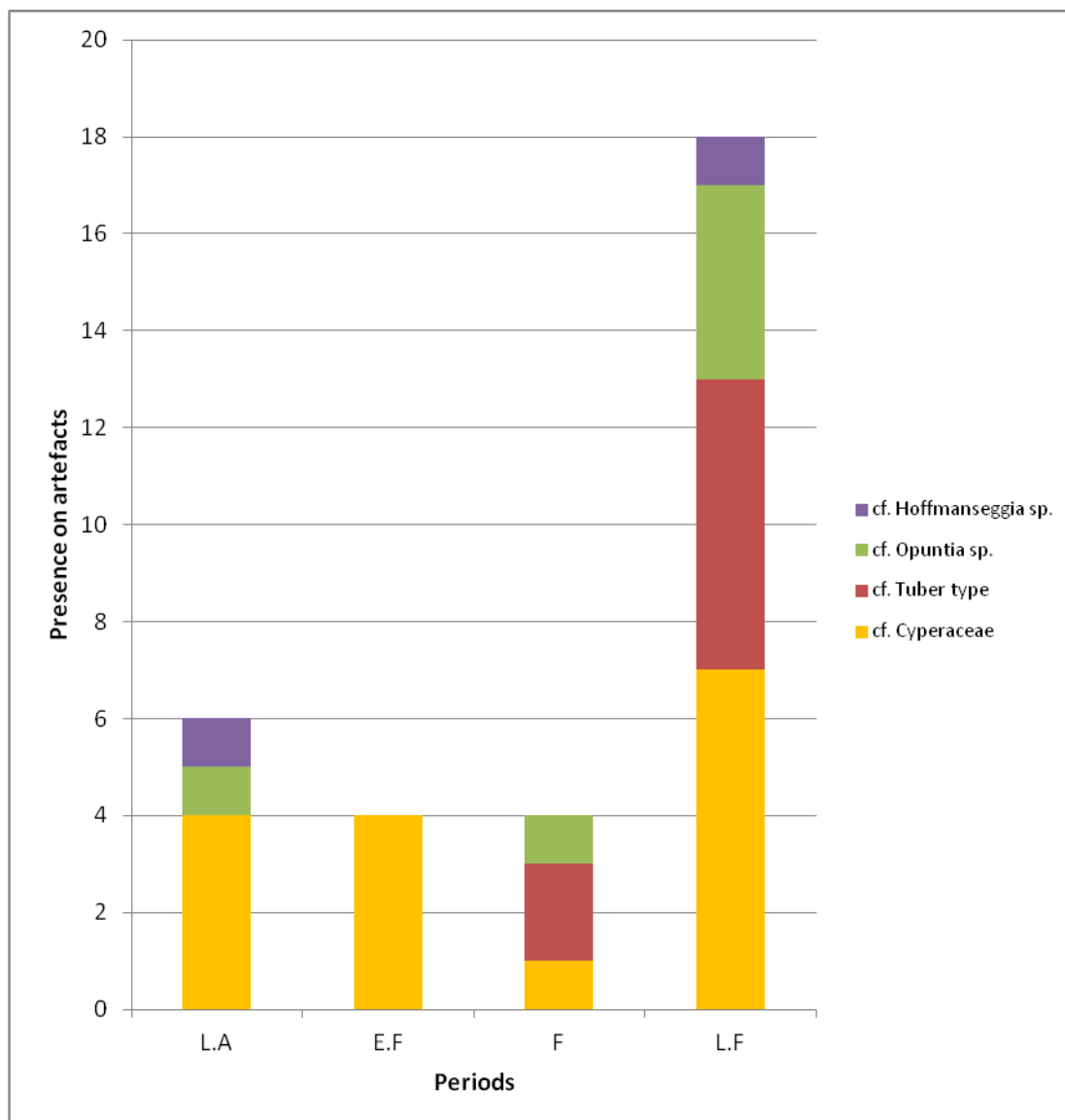


Figure 103. Presence of cacti, *scirpus* and tuber types microfossils through the whole sequence. L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).

In North America, Late Archaic skeletons from the lower Pecos had $\delta^{13}\text{C}$ collagen values that range from -15.7 to -12.6, which are consistent with CAM plants and with thirty years of coprolite analyses which show a dietary reliance on cactus and agave families as well as dental microwear caused by calcium oxalate phytoliths present in these species (Danielson & Reinhard 1998). However, the seasonal fructification of cacti in Atacama would have restricted their consumption after summer time, unless they were prepared for storage as Holden (1991) describes based on ethnographic analogies (see CH. V) or that the pads or cladodes were also eaten regularly through the year. *Opuntia* and *Scirpus* are highly

abundant in Early Formative coprolites and guts of Tulan Formative sites (Holden 1991). *Scirpus* underground organs and seeds as well as tubers have greater potential for year-round availability and storage, and hence could be a permanent source of carbohydrates. Kilocalorie analyses report high values for Cyperaceae tubers, but isotope values are not sufficiently resolute. C4 values in the apatite probably reflect direct consumption from plants such as cacti and maize in a lower proportion and C3 values in the apatite could be provided by any underground organ or Legume pods.

However, no *Prosopis* or *Geoffroea decorticans* starches were found in Late Archaic mortars. This absence of legumes in Archaic and ravine sites has been acknowledged previously (Druss 1976; Núñez *et al.* 2006; Vidal 2007), although some starch grains attached to Tulan 51 and 52 grinding tools that were not identified (McRostie 2007) could be *Prosopis*, which coincides with some minimum presence of *Prosopis* and *Geoffroea* in the Late Archaic site Tulan 52 (McRostie 2007). In contrast, it is during the Late Formative when *Prosopis* becomes the main specimen recorded on the artefacts (Figure 104), predominating in the sites of the oases, mainly in Tulo 1 and Chiu Chiu 200 and to a lesser extent in ravine sites and meadows of the Salar de Atacama, like Tulan 57 and Tulan 85 respectively.

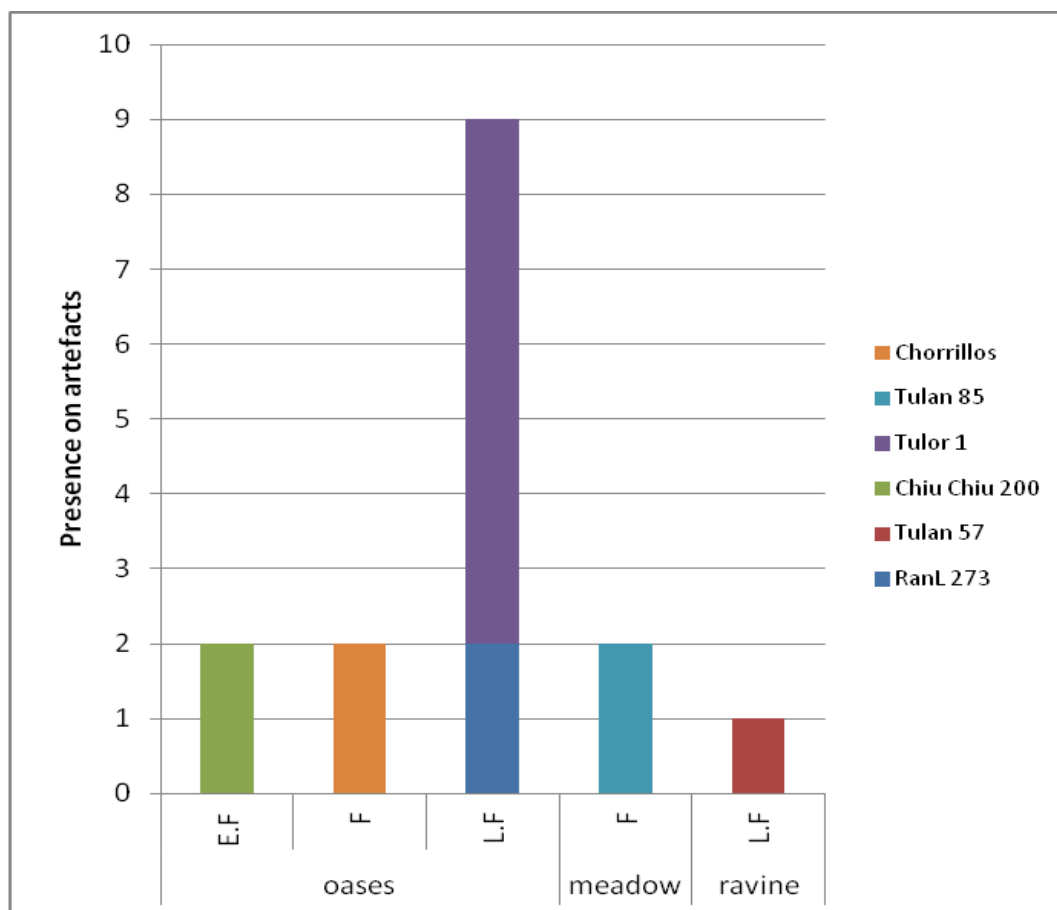


Figure 104. Presence of *Prosopis* in Formative sites and their ecosystems. E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).

This trend is also recorded by macro-remains (see Table 40). For instance, in the Tulan sequence, it is during the Late Formative in the oases and Salar de Atacama when the presence of *Prosopis* starts to become more common in the archaeobotanical record (McRostie 2008). Also this legume occurs at several Formative sites, such as Chiu Chiu 200, Tular 1, Toconao Oriente, Calar, Ghatchi 1A, Puripica and Ranl, among others (Barón 1986; Benavente 1988-1989; Núñez 1995; Orellana 1988-1989; Pollard 1971; Vidal 2007). However, greater proportions of *Prosopis* seeds in oases and ravine sites come from the Middle period if not later (Vidal 2007, 115).

The presence of *Prosopis* legumes has led Vidal (2007) and Agüero and colleagues (e.g. Agüero & Uribe 2011; Agüero *et al.* 2009) to emphasise the major role *Prosopis* had in Formative societies. Its importance in arid and semi-arid areas throughout the pre-Columbian sequence and in historical societies has also been widely mentioned by several authors. This is the case, for example, at the Ramaditas site, a Late Formative village (2500-

2000BP) located 500 kms northwest of Atacama, where even if there is evidence of *Zea* and *Chenopodium* sp., it seems that wild algarrobo pods were at the core of the community diet (Rivera 2002). Beresford-Jones and colleagues (Beresford-Jones *et al.* 2011a; Beresford-Jones *et al.* 2011b) have found in the lower Ica Valley during the Ocucaje 3 phase (750BC) that early societies did not rely on crops but on Huarango (*Prosopis*) trees and other riparian wild species as well as marine resources. In Meso-America “*Prosopis* pods constitute the second most important dietary component in human coprolite analyses in all cultural phases after 3500BC and no doubt in earlier phases too” (Callen 1969, 239 in Beresford Jones 2004). In Argentina, different parts of this fruit have been found at archaeological sites in the Northwest, Centralwest and Argentinean Patagonia. “They have been recovered at archaeological contexts dating from prehistoric hunter-gatherer occupations (10550±300BP) up to the Inka period (475±414BP) and Historical–Aboriginal times” (Giovannetti *et al.* 2008, 2976).

Regarding the trends in the presence/absence of *Prosopis* through time, Druss (1976) proposes an abandonment of the oases during summer to explain this absence of *Prosopis* pods in the Chiu Chiu complex sites. Núñez *et al.* (2002-2005), referring to their absence on Tulan, propose that these resources could have been processed in the oases and then brought as flour into the ravine sites, thus explaining their minimum presence; however, the mortars have been found in the ravines and not in the oases, making this possibility seem less plausible. Holden (1991, 328) states that “above, a number of highly productive food species, notably *Prosopis* sp. and *Geoffroea decorticans*, grow in abundance at the nearby oases of Tilomonte (only 2-3 hours away on foot from any of the above mentioned sites)... None of them have, however, been recovered from any of the sites studied. Surely, the sweet and highly productive tree legumes from the Tilomonte oases could not have been overlooked by the population and would have been exploited at the appropriate times of the year. The fact that they were not brought to the sites of Tulan 54 and Tulan 58 therefore suggests that the inhabitants must have moved down to the oases for periods of time to collect the legumes and that Tulan 54 was not a year-round occupation site”. However, habitational sites in Tilomonte oases have not been found and the scarce evidence of this period within the oases cannot be compared to contemporaneous ravine or meadow

occupations. Kilocalorie models, which could explain a restriction in their intake in order to limit the consumption of too much protein in desert environments (Seely *et al.* 2006), appear not to be a pertinent explanation from a nutritional perspective, because these pods mainly provide carbohydrates, which help to reduce water requirements (D. Matesz pers. comm. 2013), and therefore their consumption could beneficially complement a meat diet without any problem.

We need better reasons to account for the absence *Prosopis* pods on the artefacts and sites of the Late Archaic and their incipient presence in Early Formative sites. One, as already mentioned (Holden 1991), is that pods from the oases trees might have been eaten raw or without prior processing when this fruit matured, in temporary or non-structured oases sites, rather than being transported to the main sites and ground on stone tools. Main campsites during these periods were more focused on the exploitation of ravine resources such as animals and herbaceous plants, so a reduced mobility strategy might have been conditioning how the resources were exploited. A second explanation is that the costs of processing the pods and seeds (see question 3) were too high for these hunter-gatherers and incipient herders. In gathering societies roots and tubers were preferred because they require less effort in processing and have higher or similar energetic returns to seeds (Pintar 2008, 139). Dried *Scirpus* rhizomes, for instance, have even more kilocalories than *Prosopis* flour and therefore could be preferred. However, this could explain the absence of *Prosopis* on grinding tools but not entirely the lack of macro-remains if we acknowledge their disposition to be eaten raw as well the low costs implied in their harvest. A third explanation is taphonomical, as *Prosopis* does not preserve in an easily identifiable form. At a microfossil level, it has a low presence of starches and does not immediately liberate them when ground (Giovannetti *et al.* 2008) and at a macro-remain level their remains are scarce and deteriorate rapidly during a variety of common preparation methods in the Andes (Capparelli 2008), although remains such as seeds, for instance, could still be visible (Llano *et al.* 2012). On the other hand, the lack of *Geoffroea decorticans* in the samples (except for one potential starch of this specie) could be because, as ethnographic practices and ethnohistoric texts suggest, there was no need to grind these fruits (Latham 1936b; Villagrán *et al.* 1998a; Villagrán *et al.* 1998b) and this is also true for other residue analyses

on the Northwestern Argentinian Highlands (Babot 2004). At the level of macro-remains, common preparations in the puna might also have affected their preservation (Latham 1936b), though their almost total absence in Late Archaic and Formative sites (Belmar & Quiroz 2005; Druss 1976; Holden 1991; McRostie 2007; Vidal 2007) is strange when acknowledging the hard consistency of their endocarps and their assumed recurrent utilization. Also in Tulan, where coprolites and intestinal guts were examined, neither of these resources was present (Holden 1991). Thus, more analyses should be done in order to understand the causes of this repeated absence in numerous sites.

Hence, a fourth and more audacious hypothesis is that these forests were not “wild” in the oases but their increasing presence was due to human planting and management of these trees. Paleoenvironmental proxies do not provide evidence for the existence of these forests during the periods studied, though *Prosopis* has been growing in northern Chile since the Pliocene and Pleistocene (Kalin-Arroyo *et al.* 1988; Nester *et al.* 2007). However, it is interesting that in fluvial terraces in the Pampa del Tamarugal basin (21°S), Nester *et al.* (2007) found *Prosopis* remains in two wetter events, the first one shows pollen around 16380 to 13740BP, during the latest Pleistocene, and a second event occurring during the Late Holocene between 1070BP and 700BP, during the Medieval Climatic Anomaly contains almost pure *Prosopis* sp. macroremains associated to archaeological debris (Nester *et al.* 2007, 19724). Gayo *et al.* (2012a), regarding the Late Holocene presence of *Prosopis* on Pampa del Tamarugal, state that “it may be related to the presence of a farming society that significantly transformed the watershed landscape...there is a clear human factor behind the presence of *Prosopis* in our deposits. These trees have been planted and exploited for centuries by local populations for shade, food resources, fuel and building materials. Based on the above, we argue that this was the result of increased and persistent surface runoff that sustained these agriculture practices for hundreds of years” (Gayo *et al.* 2012a, 295). So was *Prosopis* able to colonise the area once water was available or are they related to human presence? The above authors do not specify the species of the earliest *Prosopis*, though if they were *tamarugo*, this could be related to the native habitat of this species (Barros & Wrann 1992; Galera 2000; Gayo *et al.* 2012a) because by now the earliest date of human presence in northern Chile is around 13000BP (Santoro *et al.* 2011). For the latest

events, Gayo *et al.* (2012a, 294) say that they could be *Prosopis alba* or *Prosopis tamarugo*; however, *P. tamarugo* has a native presence, though *alba* and *chilensis* were introduced (Gayo *et al.* 2012b).

I have already mentioned the imprecise knowledge about the species of *Prosopis* forests in the Atacama: so far, it seems that *alba* and *chilensis* are the predominant species. Muñoz (1973), Barros and Wrann (1992) and Burkart (1976) state that *P. chilensis* would not be native to the Atacama area but originates further south. *Alba* is found scattered in the semi-arid areas of Peru and *Prosopis alba* var. *panta* is found in southern Bolivia and (presumably) northern Chile. It differs from *P. alba* in having almost straight legumes (some of which may reach 30 cm in length), and in its more obtuse leaflets and reddish branches (Galera 2000). Felker and Ydeberg (1995) say that *P. alba* is native to the plains and low sierra of subtropical Argentina, extending into Uruguay, Paraguay, southern Brazil and Peru (Burkart 1976) up to 1500masl elevation. Barros and Wrann (1992) state that *alba* would be native to Atacama and Carevic *et al.* (2012) state that both *alba* and *chilensis* would be part of the natural population of the area. However, most of the studies are not precise regarding whether they refer to their current distribution or their biogeographical trends.

Hence could it be that *Prosopis* were not naturally available on the oases during the Middle Holocene and early Late Holocene or at least were rare and sparsely distributed? This could explain the near absence of these resources in Archaic sites, the almost exclusive presence of grinding tools in the ravines and the lack of oases sites during Archaic times and maybe further changes in technology and subsistence patterns during the Formative period.

Hughes *et al.* (2007) and Zárate (1997; 2000) have referred to the cultivation and eventual domestication of Fabaceae: (Mimosoideae) trees such as *Leucaena* in Central and South Mexico. Based on ethnobotanical, archaeological, geographical and genetic data; they have tracked different paths to domestication or multiples predomestication cultivation in space and time. For instance archaic foraging from wild living populations has been recorded in Tehuacan, Taumapilas and Oaxaca since 6000BP; with the first cultivated specimens appearing around 3200BP “marking the start of cultivation of *Leucaena* in the Tehuacan valley” (Hughes *et al.* 2007, 14391). But also no evidence of wild stands of *Leucaena* in some

areas and the wider distribution of *Leucaena* outside its natural range in present days suggest intensive translocation and spread by humans (Hughes *et al.* 2007).

The idea of human dispersal and domestication of *Prosopis* through the Holocene is not new (Beresford-Jones 2011; Pasiecznik *et al.* 2001; Whaley *et al.* 2010). Palacios and Brizuela (2005), state that the morphological affinity between individuals from distant localities involve a precolumbian connection and that these “algarrobales” were planted by these pre-Columbian peoples. “The algarrobo forests of San Pedro de Atacama (Chile), describe by Oviedo and Valdés (1535), deserve special mention because they are a product of the activity of the farmers that inhabited the San Pedro oases. Is not clear from where the founding seeds came, the exo-morphological analyses suggests similarities with individuals of *P. alba* from some localities of Salta (Argentina)” (Palacios & Brizuela 2005, 42) (translated by V.McRostie). This same statement is pointed out by Ehleringer (1992, 316), who states that *Prosopis tamarugo* is native to the Pampa del Tamarugal, whilst *Prosopis alba* was introduced from Argentina in pre-Columbian times. Hence, could *Prosopis* be carried and adapted to the area just like other cultivated plant? Is it a coincidence that in the tombs of Toconao Oriente, which represent the phase of greatest “orientalization” in the oases of the Atacama (Tarragó 1984, 97), there is *Prosopis* but not maize?

At present, it is impossible to determine whether these forests of Atacama are anthropogenic or natural, though the two alternatives imply distinct trajectories and cultural implications. In the Atacama area, there is no ethnobotanical information regarding the management of *Prosopis*, although Casas and Caballero (1996) give some concepts when recording ethnobotanical management and perception of *Leucaena esculenta* “guaje” in the Mixtec Region of Guerrero, Mexico. They recognise three forms of management for these trees: cultivation, gathering from purely wild populations, and selective retention of particular individuals in disturbed areas. Cultivation consists in planting preferred varieties in house gardens or agricultural fields. They sow selected seeds either from wild or cultivated trees, directly onto the earth or into seedbeds. Tolerance in disturbed areas consists in leaving the sweet *guajes* and cutting the undesirable or bitter trees. Harvesting of wild trees is selective. They usually harvest the sweet individuals and they know exactly

where these can be found. Wild populations selectively managed showed that people are able to modify the phenotypic structure of plant populations (Casas & Caballero 1996, 177).

Then, for Atacama, one scenario could start through the cultivation stage whilst the other could start with food procurement or mainly a gathering strategy. As Harris (1989; 1996a) states, the path from gathering to farming is not unidirectional. In *Leucaena* and *Prosopis*, wild and cultivated stands coexist. Introduction of *Prosopis* in different countries of the world has shown that they rapidly become naturalised and have extended widely within those countries (Galera 2000): hence, after either a first cultivation or approach to these forests, different types of management could have been practiced. Both initial stages could have happened around the Late Archaic and the Early Formative, though by the Middle and Late Formative, activities such as tolerance or selective gathering, among others, could have been taking place and intensified by social demands (Agüero & Uribe 2011; Vidal 2007). Hence, this could represent an increased level of human-plant interaction where *Prosopis* forests were expanded and managed, playing a substantial role in the possibilities and quality of human settlements in the oases through time. “No other desert tree has a more pervasive influence upon neighbouring vegetation, soils, sub-canopy microclimate, wildlife and insect populations” (Beresford-Jones 2004, 470). “The majority of the species of *Prosopis* are important in the fixation and restoration of the soil because they contribute to its development” (Galera 2000, ¶ 34, translated by V. McRostie).

In the case of the known specimens for the study area, *Prosopis alba* can be multiplied either vegetatively or by seed. However, *Prosopis* seeds have an imposed latency due to their hard tegument so that mechanical scarification by people could aid their germination. Afterwards, irrigation and pruning are recommended, and depending on whether the aim is for agroforestry or silvipastoralism (See IX.2 below), the intervals between plants may vary. These species can be planted with maize or tunas and can be used as forage and refuge for animals, promoting multiple use of the ecosystem. Regarding *Prosopis chilensis*, the best propagation is by seed, but it can also be propagated by vegetative methods. In nature, germination is favoured by endo-zoochory. Seeds without pre-treatment do not go further than 28.5% to 44% germination. Both *P. chilensis* and *P. alba* are species highly desirable for human populations because of the agroindustrial value of their fruits and wood (Galera

2000). *Prosopis alba* var. *panta* is distinguished essentially by its bigger, succulent and good quality forage fruits with higher protein and lipid contents (Galera 2000). Indeed, various studies have been conducted to domesticate *P. alba* var. *panta* for agroforestry purposes (Galera 2000). Beresford-Jones *et al.* (2009a, 305) mention that “those specific traits observed in *P. pallida* of the south coast of Peru and so widely appreciated in the agro forestry literature, may be the product of long processes of human selection”. Hence, this ongoing relationship between humans and plants has probably modified this genus as well as the oases’ landscape (Clement 1999; Smith 2006; Terrell *et al.* 2003). Palacios and Brizuela (2005) suggests that if these forest were planted by people, then domestication did happen, though similar to other cultivated species of America (Clement 1999), their cultivation did not persist when Spaniards arrived. However, at this point and with the available data, the nature and stage of this domestication cannot be fully addressed. But I can suggest that these trees were more than wild or in an incidentally co-evolved stage, and were somewhere between incipiently domesticated and semi-domesticated (Clement 1999), as Martínez (1998) has already proposed. Hence, it is quite probable that *Prosopis* should be placed in my “uncertain” category rather than in the “wild” one.

Potential crops such as *Zea/Prosopis*, Cucurbitaceae and *Capsicum* are exclusively present in the oases in sites such as Tulo 1 and Chiu Chiu 200. Tulo 1 presents both a continuity of traditional resources and the adoption of plant innovations. The presence of these crops at a microfossil level confirms previous macro-remains findings (Barón 1986; Benavente 1988-1989; Holden 1991; McRostie 2007; Núñez *et al.* 2009; Tarragó 1989; Vidal 2007). Regarding the variety of the maize found, this cannot be determined with the starches recovered, especially considering the redundancy with *Prosopis*¹⁶. In the future, DNA analyses could be used to discriminate between these starches. Maize is a highly plastic and adaptive crop, which does not require permanent care (Minnis 1992; Raymond & Deboer 2006), and

¹⁶ Unambiguous identification of *Prosopis* is possible due to the irregular starch grains in this species, whilst redundancy with maize is due to the regular starch grains (See results chapter).

therefore could have been grown in small amounts, though there is no evidence to discriminate between local and non-local production. Regarding Cucurbitaceae starches, these are redundant between species; however, *Lagenaria* rinds are present in almost all of the sites of the area, so its presence as starch is not a surprise. Its low frequency might reflect no processing or manipulation, as I will discuss in the next questions. The confirmation of the crop cf. *Capsicum* requires further research, although it could be present, as it was previously identified as a seed in Tulan 58 (Holden 1991) and the *Capsicum* genus has been present in the Andes since the Late Archaic (Muñoz 1983; Pearsall 2008; Perry *et al.* 2007; Santoro 1980). Finally, pseudo cereals, which have been reported in the Bolivian Highlands (Bruno 2001; 2006; Bruno & Whitehead 2003; Langlie *et al.* 2011; Nordstrom 1990) and Northwestern Argentina (Babot 2004; 2005), were not confirmed in my samples, other than some clusters similar to Chenopodiaceae (Babot 2004) and one oxalate with similar characteristics to oxalates in seeds. In the Atacama area cf. *Chenopodium* seeds (Belmar & Quiroz 2005; Benavente 1988-1989; McRostie 2007; Vidal 2007) have been found in different sites, though their status as a domesticate is still not certain and the presence of clear wild specimens of the same family makes this more confusing. Recent analyses in the highlands of Bolivia (Langlie *et al.* 2011) have shown that the process of domestication of pseudocereals might present a wide range of specimens and morphological traits with characteristics that are hardly known today. However the techniques of planting and harvesting of *Chenopodium* plants are less likely to leave residues on hoes, and the small *Chenopodium* seeds are also less likely to be ground in mortars, so the lack of microfossils may reflect the differential processing of these plants.

Overall, the low presence and tentative identification of crop starches do not permit further conclusions about the cultural implications of this data. Confirming archaeobotanical macro-remains, traditional crops (domestic) are still very scarce when compared to wild and uncertain resources (Figure 105) and in some cases their domesticate status is not secure (e.g. seeds of *Chenopodium* and starches of maize).

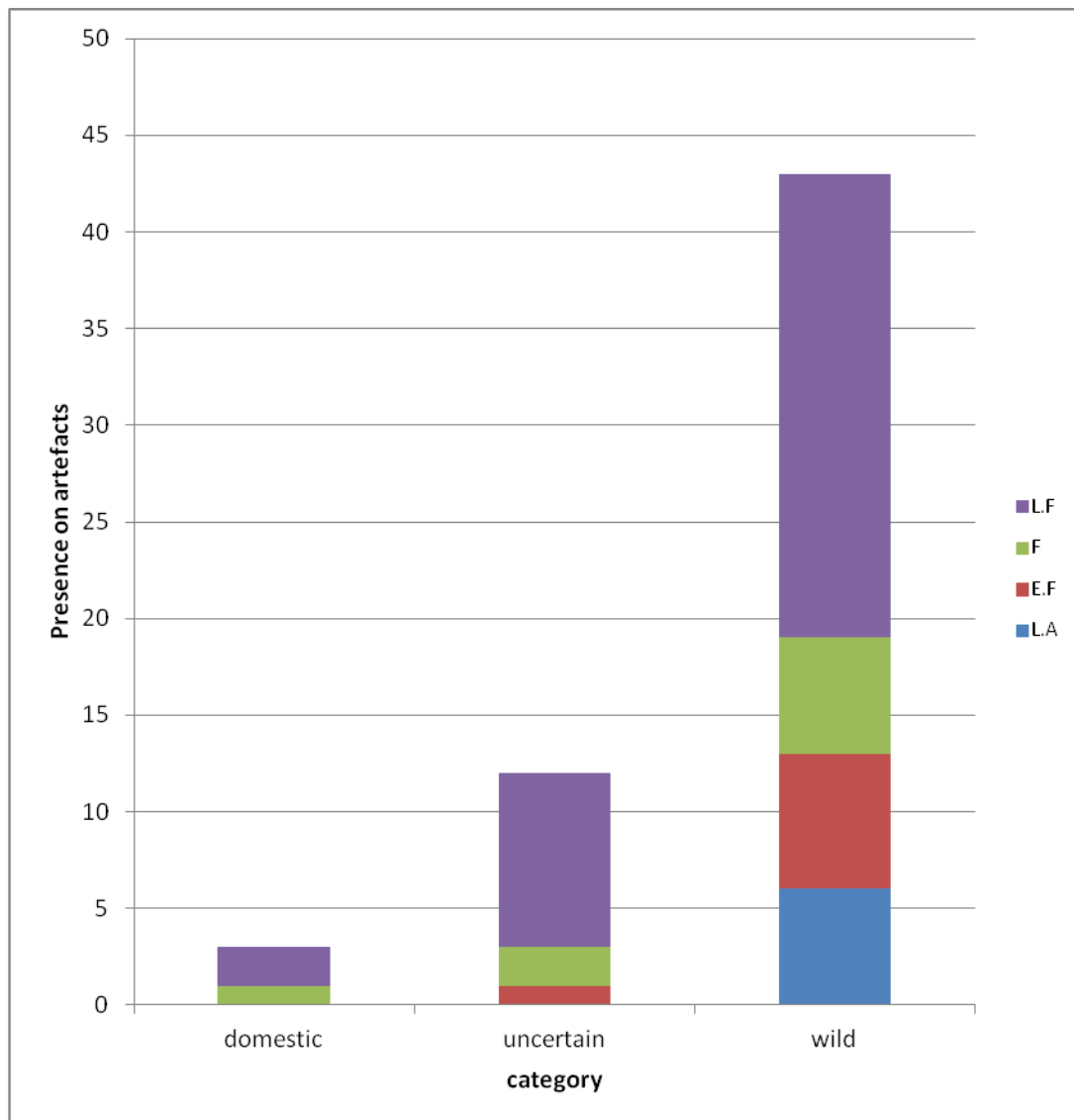


Figure 105. Categories (domestic-crops-, wild, uncertain) of plants in L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).

Regarding differences in space, a pattern arises with the fact that there is a difference in the evidence of resources in the ravines versus oases (ravine resources prevail on the artefacts in the ravine sites and inversely oases resources, such as *Prosopis*, prevail on artefacts in the oases) (Figure 106). This could support the suggestion of reduced mobility, at least for some part of the community (e.g. women who are likely to be the main gatherers) (Kelly 1992; Pintar 2008), who could also have looked after initial cultivation or/and management of *Prosopis*.

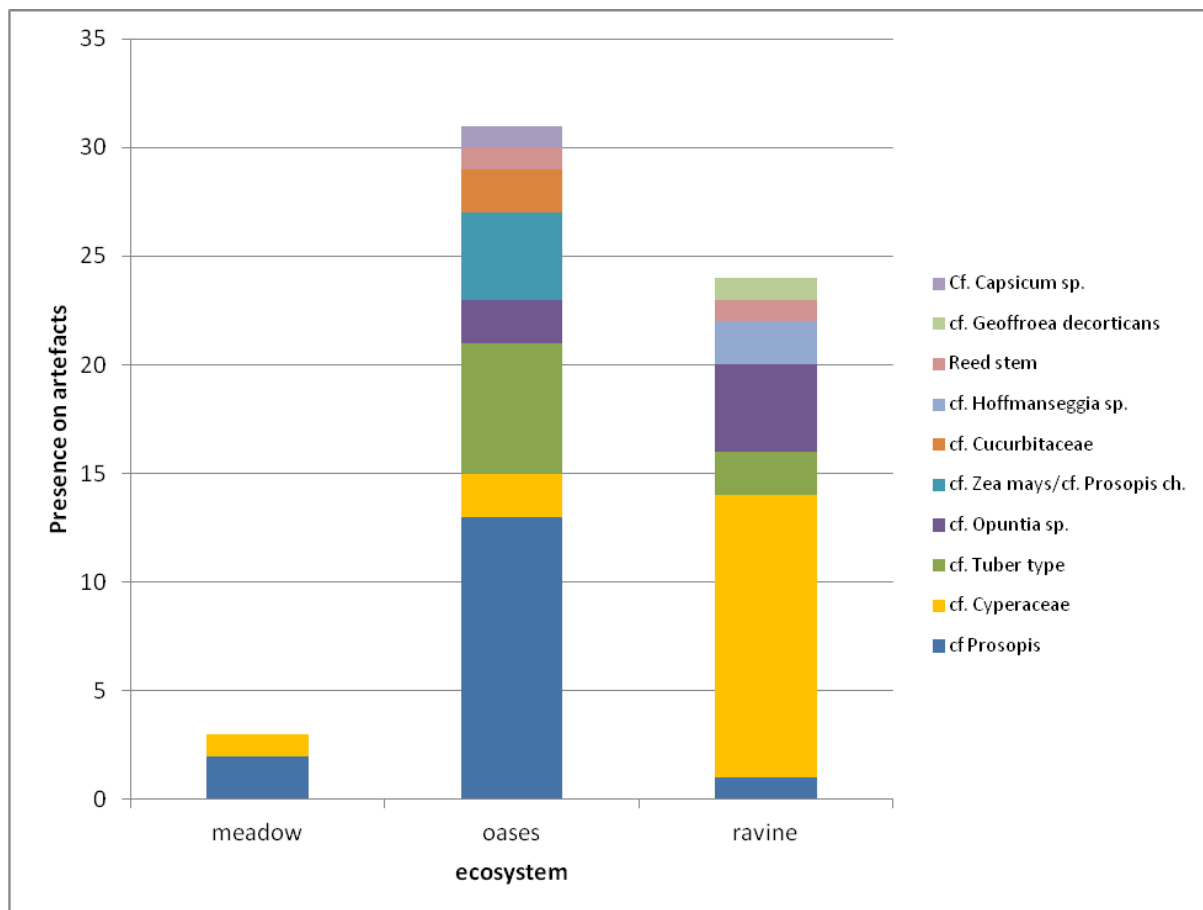


Figure 106. Resources versus ecosystem site location.

Scirpus nevertheless grows in both ecosystems but *Prosopis* seems to undermine its presence in the oases or replace it in the diet, especially in Tulor (Figure 107). Tuber types are present mainly at oases sites, and if these were locally managed rather than brought from other areas, it might be that ecological conditions were more favourable for this taxon in the oases. “Under an agrarian system the natural habitat of a plant must be replicated... and the ease with which this is possible is related to its likelihood to being cultivated. This is especially true for roots and tubers...” (Hather 1994, 719).

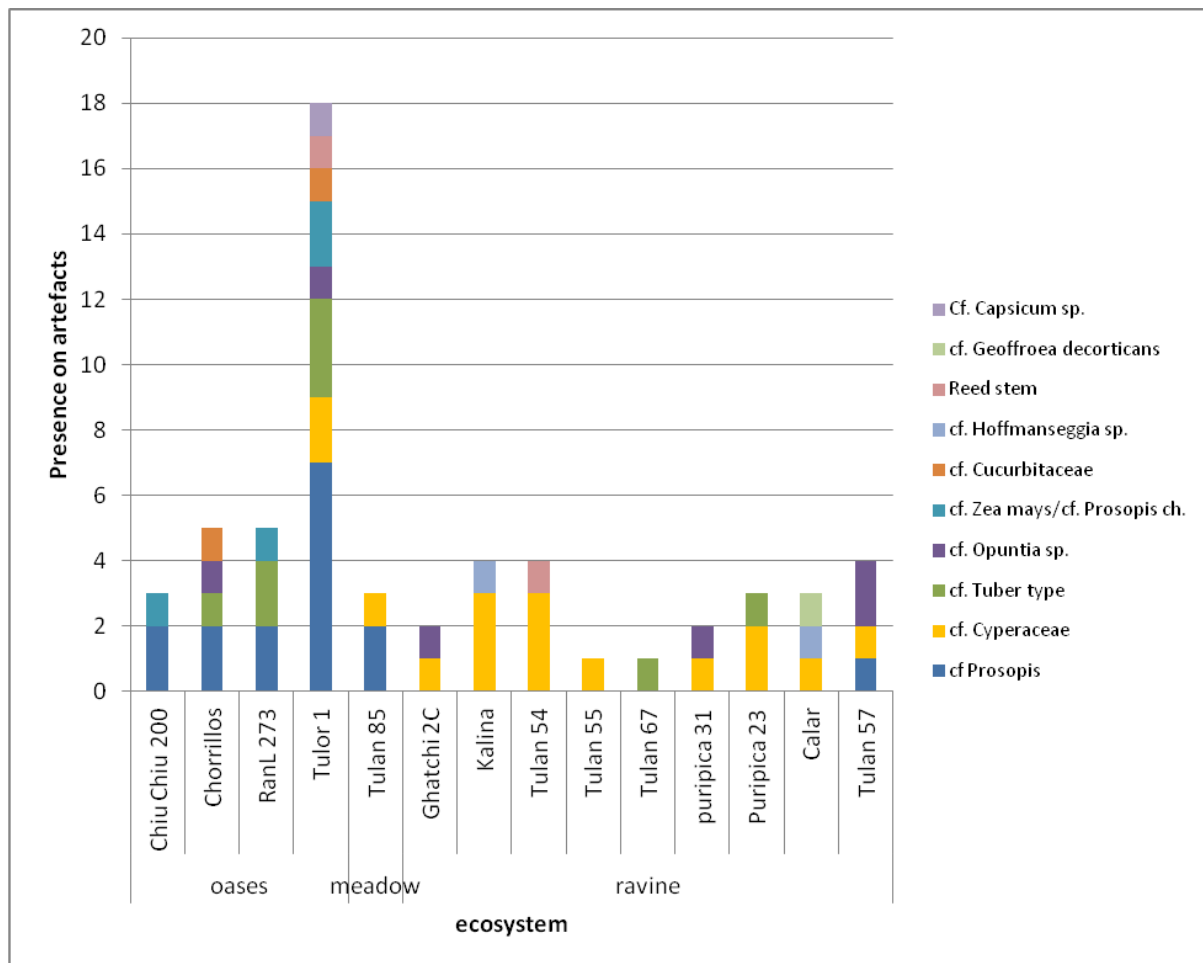


Figure 107. Presence of taxa on artefacts from sites located in oases, meadows and ravines.

This pattern could be explained as a reduced mobility and is consistent with the semi-permanent and permanent settlement pattern described for complex hunter-gatherers worldwide and in the development of more sedentary life and increasing specialisation. In fact for the Late Middle Holocene (4000BP) in Northwestern Argentinian Puna, Hocsman (2002) highlights archaeobotanical remains as one indicator of reduced mobility in QS3 and Punta de la Peña (Rodríguez 1999a; 1999b; 2000). The area of collection of plants could vary from 0 to 3km to collect wood for fire and 0 to 20km when special plants are required (Hocsman 2002, 200). Hence the management of these plants could be related to a growing sense of property and land ownership that a reduced mobility could have encouraged (Yacobaccio 2001).

However, the establishment of more sedentary campsites, at least in the puna and Andean societies, were always complemented with different strategies to have direct or indirect

access to different resources (see question 4 for broader discussion). This complementarity between ravines and oases has been positively documented in Vilama, Ghatchi, Puripica and Tulan among others sites in the ravines, at the time when oases sites are more consistently occupied (Agüero 2005; Núñez 2005), and could explain that even if proximate plants prevailed in the sites, these are combined with plants from the other ecosystems.

Other ways to complement our knowledge about plants used in subsistence are the signals obtained from $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ from the isotopic analyses of bones from Formative cemeteries. However, as I showed in the results, these signals are not easy to interpret due to the range of C3 and C4 plants present in the area, which could enter the diet either directly and/or indirectly (via meat consumption). This situation becomes less clear when considering the uncertainties of fractionation models and the incomplete reference collection I managed to collect for this particular part of the research. I cannot establish which taxa were used, but only give a rough idea of C4 versus C3 proportions and the trophic level of some individuals. The interpretation of the proportions in which different photosynthetic plants are eaten depends on the fractionation model used for the apatite; so when using a +9.4 model, 42% of the individuals present a low-medium intake of C4/CAM (10%-40%); whilst with the +12 model, just 15% of the individuals present a low C4/CAM consumption in the whole diet (10%). In both cases, C3 represents the remaining proportions which are bigger than the 50%. These C4 plants could be CAM (*Opuntia*, *Echinopsis*), as these have high $\delta^{13}\text{C}$ values and are well represented in the archaeobotanical record (Holden 1991; McRostie 2007; Vidal 2007); though maize could also be consumed incipiently and perhaps with more frequency in ritual or social gatherings, as was previously proposed in Tulan 54 (McRostie 2007), an interpretation that is quite widely accepted in the Americas (Benz & Staller 2006; Burger & Van der Merwe 1990; Hastorf & Johannessen 1993; Logan 2006; Staller 2006b). The C3 component could be due to a range of plants, including tubers, Cyperaceae (but see Cadwallader *et al.* 2012, for Ciperaceae with C4 values), *Prosopis* and *Geoffroea*, among others.

Regarding the percentage of C4 in the protein, 40% of the individuals show presence of C4 between 10% and 70%. As discussed, this might be due to the enriched C4 diet of the camelids being consumed as meat and also due to the breastfeeding 'carnivorous' effect for

the two newborns of Tulan 54. The nitrogen values are hard to correlate with diet due to the strong influence of aridity; and the $\Delta^{13}\text{Cap-Ccol}$ suggest protein and plant consumption proportions in diets also varied, depending on the fractionation model used. These analyses can be compared with some the limited number of isotopic studies previously published for the area during this period. The first one used two individuals sampled from the Middle Loa in Chorrillos cemetery (González & Westfall 2006); the second to the west of San Pedro in the Salvador river valley (Knudson *et al.* 2012; Torres-Rouff *et al.* 2012), while the third study analysed $\delta^{13}\text{Cap}$, $\delta^{13}\text{Col}$ and $\delta^{15}\text{N}$ from seventeen individuals from the San Salvador cemetery (Torres-Rouff *et al.* 2012) and the fourth and last study (Knudson *et al.* 2012) analysed an adult male corresponding to the Late Formative period (1–500AD) found on a route connecting the northern Chilean Coast to the Loa River Valley. All of them suggested a mixed consumption of C3 and C4 plants and interpreted high nitrogen values as having been caused by fresh water and marine resources, though they do not acknowledge the aridity effect in these values and the fact that collagen could have been enriched by people consuming meat from terrestrial fauna that have been feeding on C4 plants. However, it is clear that during the Formative period, C4 plants were not a main staple as has been shown for later times during the Late Intermediate period (1100-1400AD), when a whole diet value of $\delta^{13}\text{Cap}-6.7$ is present in Caspana (Knudson & Torres-Rouff 2009).

Summarising my conclusions for this first question

The analyses of microfossils on stone tools has revealed some continuity as well as some changes in the range of plants present, which in most of the cases can be correlated with the limited evidence from macro-remains. I interpret these patterns as part of a risk-spreading strategy in which the continuing reliance on traditional and known plants gives some stability while the gradual introduction and increasing use of other resources permits a diversification and broadening of the diet spectrum. Reliance on the same plants through time may also represent some conservatism in food choices due to culinary traditions, taste and dietary preferences. Patterns of changing plant use in relation to the local environment are in tune with a reduction in mobility and a more settled lifestyle within the Late Archaic and Formative populations, though the complementary use of space is also shown with the cross presence of resources. These patterns of plant acquisition also open up a debate

about the division of labour and social organisation within groups (Kelly 1992; Pintar 2008). The re-evaluation of plant management in the light of evolutionary approaches allows us to explore a vast and rich universe of human-plant interaction that recalls that “crops” and agriculture are not the only avenues to complexity. Another domesticated landscape starts to arise when acknowledging the role of arid and highland plants such as *Prosopis*, Cyperaceae, Cactaceae and tubers. Therefore, this Formative period is not characterised by maize agriculturalists or horticulturalists but by societies in the middle ground (Smith 2001b), which strongly relied on camelids and “wild” plant production in which the frontiers of domestication should be further explored. Although the isotope evidence is partial, and any interpretation must be considered preliminary, nonetheless it complements the archaeobotanical record and is also indicative of a diet where both C3 and C4 plants were being consumed directly and indirectly.

2. Why do lithic hoes appear during the Early Formative? Are they related to farming practices?

The appearance of hoes during the Formative period has been interpreted as direct evidence of some kind of agriculture or horticulture. This idea emerges from an analogy with proto-historical evidence and the associations of these tools with agricultural fields (Bittmann *et al.* 1978; Le Paige 1963). With the evidence found in this thesis (either as presence and absence), I re-evaluate the farming role that has been given to this tool. In the Formative period of the Atacama, these tools might be more related to intensification activities regarding plants but also multiple tasks related to soil and water management and the construction of a more settled way of life.

Their appearance by the Early Formative could be part of a wider diffusion of techniques rather than a local invention, as this technology was present from early times, as identified in Peru during the Las Pircas phase (ca.9800-7800BP) (Dillehay 2011); in Bolivia in the Early Chiripa and Wankarani, and in the Early Formative in the northeast margin of the Uru-Uru lake (ca.1500-1000BC) (Bandy 2001; Capriles *et al.* 2011) and Northwestern Argentina in Casa Chavez Monticulo site (ca.400BC) (Pérez 2010).

The hoes analysed come from those sites where this tool has been reported to have played an important role in the construction of the archaeology of Atacama (Figure 108). These sites are located in oases and ravines where, according to ethnographic occupations, small or large patches of soil for planting could have been prepared (Barón 1986; Llagostera *et al.* 1984; Llagostera & Costa 1999; Núñez 1994; Núñez *et al.* 1999; Orellana 1988-1989; Pollard 1971).

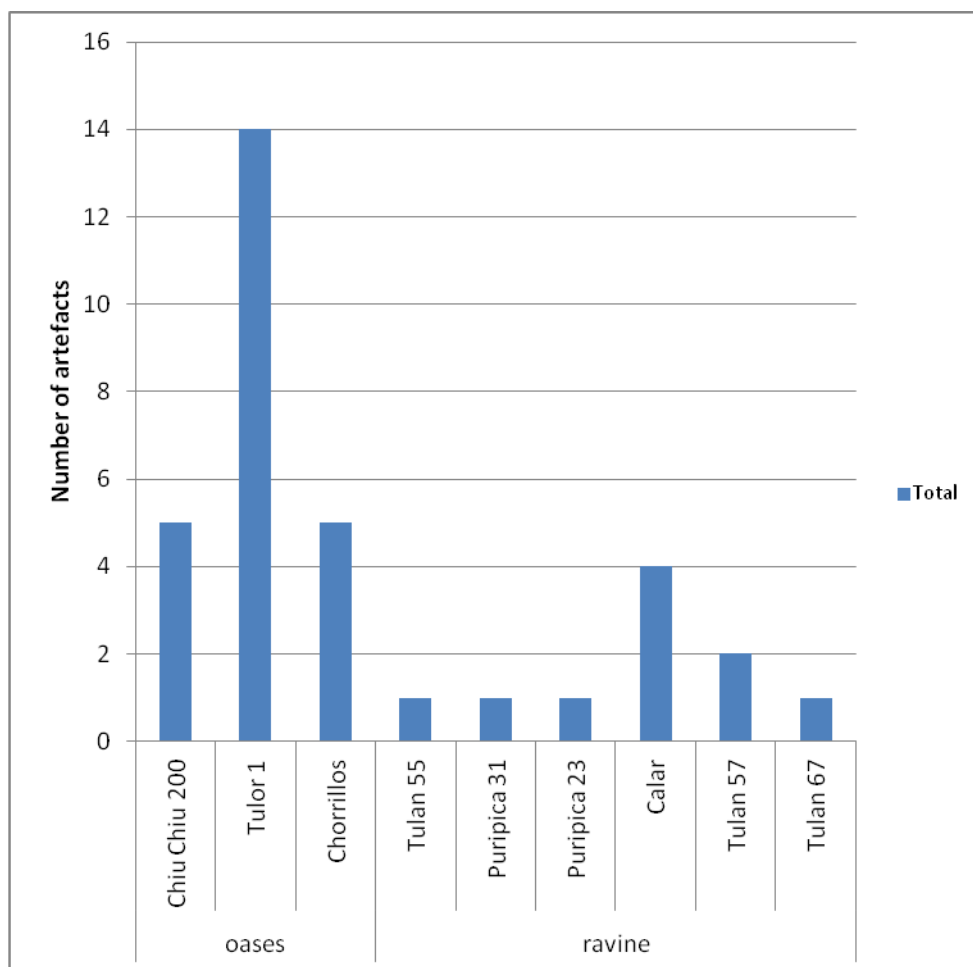


Figure 108. Sites where hoes were sampled.

Even if in Atacama there is no local ethnography about the use of lithic hoes, they were probably used in activities related to the digging and movement of soil. More efficiency would be achieved if these tools were hafted, as has been recorded in Chorrillos tombs and proto-historical samples. Keeley (1982, cited in 2010) states that an instrument is hafted to increase its strength during labour, to reinforce efficiency or precision, and to be able to position and control the tool's cutting edges, among others.

If this tool was an agricultural implement used to prepare the fields during pre- and post-harvest or for irrigation features, as has been stated; and supposing that soils in agricultural fields preserved some microfossils from the crops, at least some of them could become attached to these tools either during or after harvesting. Hence, with the available data, I can start to discard maize cultivation. Maize produces diagnostic and abundant phytoliths in the leafy structures: hence, “One would expect that if maize leaf was present in a particular context, the numbers of these phytolith forms would be elevated” (Logan 2006)¹⁷. Maize could be grown in the oases and today it is a very common crop, so the fact that there are no phytoliths on the Formative hoes makes it more probable that the maize found on sites was acquired through trade rather than produced by local agricultural activities. This would mean that the imported maize would come without external organs which have the diagnostic phytoliths (crosses, bilobes) and which have not been found either as macro remains; and in some cases might have been carried even without the cobs (which produce rondels) (Núñez 1993). The suggestion that maize could be an “exotic” or trading item is in agreement with the idea that maize in its earliest times was more a ritual food than a main staple (Blake 2006; Burger & Van der Merwe 1990; Hastorf 1999; Johannessen & Hastorf 1994; Logan 2006; Pearsall 1994; Staller 2010). Scarce macro-remains of maize have usually been found in sites which possess North-Western Argentina and/or highland pottery such as Chiu Chiu 200 and Tulo 1; and as micro-remains in highly ritual contexts like Tulan 54, where their exclusive presence as starch grains attached to mortars suggests that this crop was consumed after grinding, most likely in the form of *chicha* (McRostie 2007) and where it seems a confluence of peoples from different areas was happening or at least the use of exotic items was relevant in the social and ritual activities (Núñez *et al.* 2005). However, these micro-remains should be re-evaluated in the future due to the redundancy of starch maize with *Prosopis* as identified in this thesis. Thus, the low presence of maize macro-

¹⁷ This statement should be evaluated with further tests or ethno-archaeological studies to evaluate whether hoes used on maize fields would trap phytoliths or their different parts.

remains even during the Late Formative (McRostie 2007; 2008; Núñez *et al.* 2009; Vidal 2007), the ambiguous presence as starch grains attached to artefacts and the total absence of maize phytoliths lead me to propose that there was not a significant maize production, hence *if* maize was locally planted, then this activity was performed at a very small scale; however, there is no physical evidence to sustain the hypothesis of local production during the Formative, nor is there any knowledge of a maize surplus production in nearby areas for this time (Babot 2004; Langlie *et al.* 2011; Logan 2006; Rivera 2006; Whitehead 2007). So wherever this crop was planted, the scale of cultivation was probably small, in accordance with a non-staple production, and hence harder to detect within archaeological studies.

In contrast to the absence of maize residues, and confirming previous analyses of residues found on hoes at Tulan 55 (McRostie 2007) and also in North-western Argentina Formative grinding tools (Babot 2004) is the presence of starches from tubers in different sites and with more frequency than previous crop starches, which could be more significant for the discussion of the local production of crops (Figure 109).

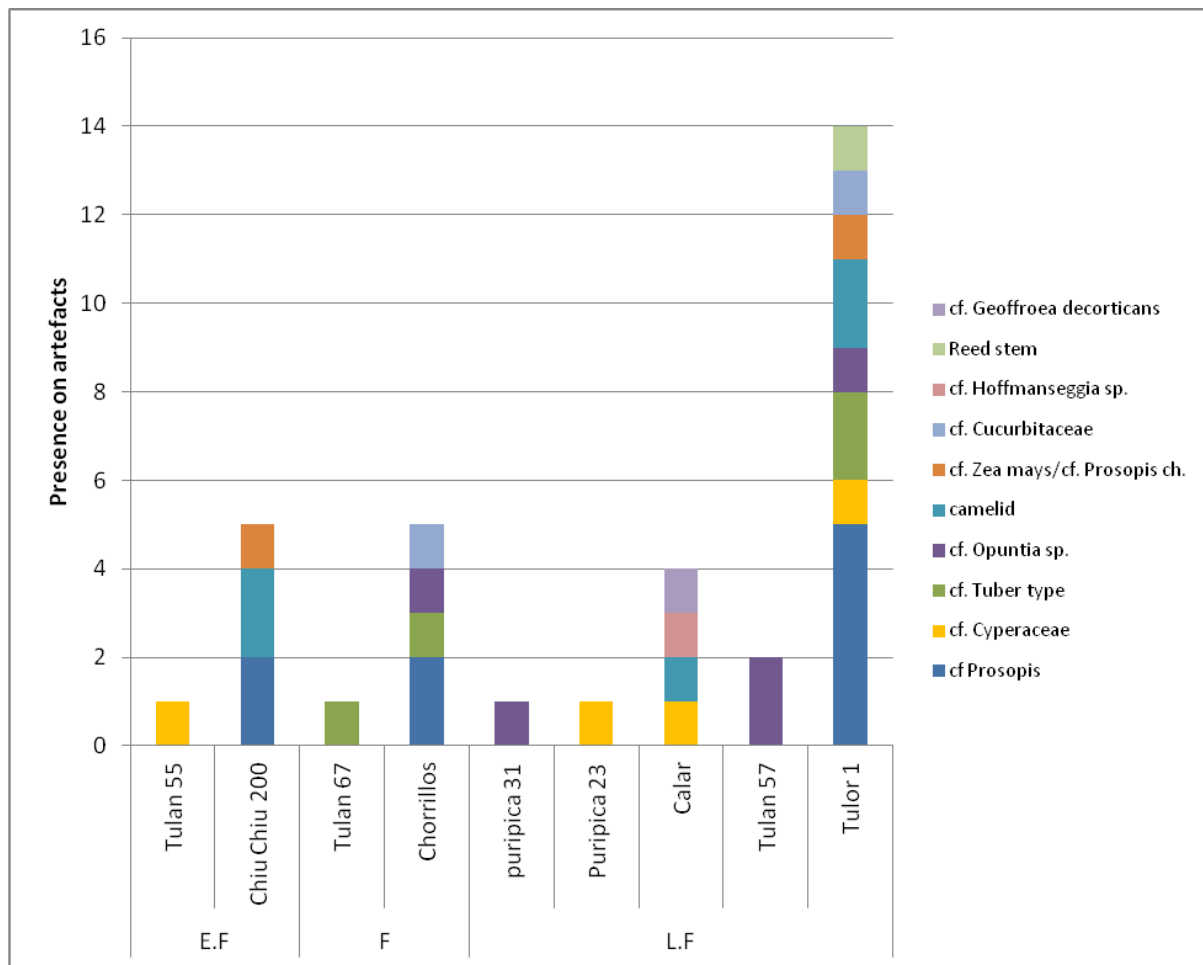


Figure 109. Presence of different taxa on hoes: E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).

Fifty percent of the tuber-type starch grains were found on hoes: thus, if some type of crop cultivation was present during this period, this could be related with the planting and harvesting of tubers rather than with maize. Residues could have attached when harvesting, dividing or tilling the underground organs. Nevertheless, their domesticated status is not secure, as I have already mentioned for the wild tubers available in the area, one of them being *Hoffmanseggia*, was identified on a Late Formative hoe. Reviewing the information about local agriculture (CH.V- Crops), potatoes (*Solanum tuberosum*) can be grown below 2000masl in northern Chile, although local and biological information states that this plant does not grow well in saline soils and under stress of water (J. Kalazich pers. comm. 2012). Nevertheless, in some oases of the Salar de Atacama, potatoes were and still are planted in small amounts (San Pedro, Toconao, Peine) and potatoes seem to be a common crop in villages settled in the Middle and Upper Loa as well as the Salado River (Castro 2008). However, it could also be that these starches became attached to hoes through other

activities and hence it is not possible to discount other mechanisms as explanations for the presence of this tuber type. For instance, today potatoes are mainly acquired from other markets. Socaire potatoes grown in upper belts are traded for oases products, or as Bertrand (1885) states, potatoes were brought from the south.

Residues from some crops attached to hoes, such as cf. Cucurbitaceae in Chorrillos and redundant starch grains (*Zea/Prosopis*) in Chiu Chiu 200 and Tulor 1, are not diagnostic or frequent enough to propose that they originate from any cultivation. The former might not be maize at all and I have already referred to the lack of maize phytoliths. Also there is no reference of local pre-Columbian cultivation of Cucurbitaceae in the area, although today people grow squashes and their weedy characteristic as well as their early presence in the Andes (Lema 2009) makes them a potential crop, but this should be evaluated with further analyses.

Besides this potential association to cultivation of domesticates, these hoes could also have been involved in the care, cropping or processing of wild plant foods (Ford 1985; Harris 1989). Hoes could be used for a range of activities such as tending, sowing, transplanting and tilling (Ford 1985). For instance, 83% of *Opuntia* microfossils were attached to hoes, so it seems likely that this tool was used to manoeuvre this spiny plant and for transplanting in home gardens, for instance, as in the Mexican example mentioned previously (Casas *et al.* 1997) or as local people remember (O. Mora pers.comm 2013). The presence of Cyperaceae on hoes could be related to tilling as well as digging *Scirpus*, as proposed for the Titicaca area (Whitehead 2006) and could be supported by ethnoarchaeological studies, which state that the uprooting of the tubers requires a concerted effort (Wollstonecroft & Erkal 2003). Hence, hoes could have been related to intensification practices. This possibility starts shifting the idea that rivers, meadows and streams as well as hoes were related exclusively with production of crops. These water areas could be managed and used as larders for resources such as *Scirpus*. Also the fact that *Prosopis* is present on the hoes sampled from oases sites (Tulor 1, Chiu Chiu 200, Chorrillos) could be related to activities associated with the management of these forests. Therefore these hoes could be related to intensification practices whose aims might have varied as social contexts adjust to different cultural and natural scenarios.

But this tool is not just related to plant manipulation. As stated by several authors (Haber & Gastaldi 2006; Núñez 1992; Pérez 2010; Tamblay 1990; Whitehead 2006), this tool is useful for multiple purposes, such as soil removal, digging pits and building houses, and could be closely related to the more sedentary pattern seen in Atacama. Most of the hoes sampled were found inside the structures (Tulor 1, Calar, Tulan 55, 57, 67, Chiu Chiu 200, Puripica 31-23). The reduction of mobility implies a change in refuse and debris management (Kelly 1992) and therefore cleaning the sites could be a strategy to improve hygiene conditions. Hence indirectly the presence of hoes might be reducing productive risk. Could it be that the necessity to prepare habitation and corral structures and to maintain them clean of debris and soil, or to rotate and collect dung for different tasks, such as fuel for fires and fertilizer, could produce the multiple microfossils seen in my samples?

It is relevant that camelids' spherulites (Figure 110) were mainly found attached to hoes (83%) in Calar, Chiu Chiu 200 and Tulor 1. Dung is a major by-product of camelid herding that can be collected from corrals and is widely used in the Andes (Sillar 2000a). Its role as fertiliser in the highland and desert environments (Gundermann & González 1995; Korstanje 2005) of the Andes is an interesting possibility to explore in the future.

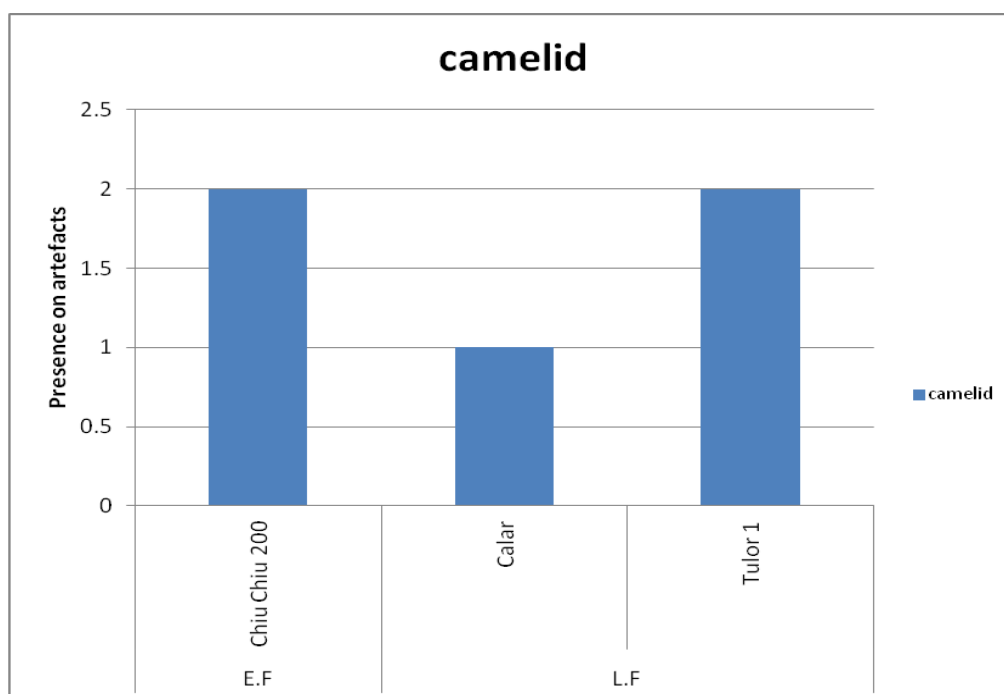


Figure 110. Sites where spherulites were recovered from hoes E.F: Early Formative; L.F: Late Formative.

Summarising my conclusions for this second question

The analyses of residues on stone hoes primarily relate them to the care and collection of wild foods rather than the production of domesticates. *Prosopis*, *Scirpus* and *Opuntia* are potential wild species that could be intensified with the help of these tools and hence a gradient continuum of plant interaction can be proposed from this perspective. Activities such as tending, tilling, transplanting or cutting could have required the use of this technology. Regarding the cultivation of domesticates, although I cannot entirely discount this potential use, I suggest that this could be better represented by some type of tuber rather than maize; however, tuber taxonomy is still uncertain. Nevertheless, hoes are generally multifunctional implements and hence, they reflect a changing engagement with earth and plants rather than a particular activity. They could be used in diverse activities that were acquiring more relevance during the Formative period, such as soil removal for building houses; cleaning debris and managing the dung from domesticated camelids. Hence this tool also strengthens risk-spreading strategies by both maximising off-take and enhancing carrying capacity in different ways and with different resources.

3. Why were new grinding technologies adopted? Are they related to new resources (crops)?

Morphological change in grinding tools cannot be linked to any specific resource, as there are both continuities and variations in the taxa identified through time; neither are they correlated to crops (as opposed to wild foods). So what I suggest, based on the results, is that the adoption of these tools was more related to the selection of different characteristics that facilitated finer grinding suitable to diversify cooking recipes but also to gain more productivity and less effort in the processing. This change in technology permitted efficiency in the processing of larger quantities of material, which might have allowed delayed consumption, easier transportation, more free time and/or a higher amount of surplus, especially by the Late Formative, when social pressures seem to be stronger. Also, future wear analyses should look for abrasive marks that could be linked with the polishing of beads, as Wright *et al.* (2008) have found in eastern Jordan.

Like the evidence for maize and hoes, these flat mortars seem to predominate in sites with strong evidence of interaction (Tulan 54, Chiu Chiu 200, Tulor 1). Flat mortars have been identified at various sites of the Andean Formative and even earlier in the Las Pircas Phase (9800-7800BP) of Northwestern Peru, in Chiripa in the Early Formative (1500-1000BC), and in North-western Argentina (3450-1300BC) (Babot 2004; Babot 2006; Hastorf 2003; Rossen 2011). General patterns inferred from the Late Archaic and Formative grinding tools sampled show that for the former, *Scirpus*, *Opuntia* and *Hoffmansseggia* are present, and in the latter, although very small amounts of residues of tuber types and redundant maize/*Prosopis*¹⁸ starches are found, the predominant resources are *Scirpus* and *Prosopis*. This evidence shows that it was the wild resources that prevailed in the sequence from the Late Archaic through the Formative period and the morphological change in the stone tool technology does not relate to crop processing (Figure 111).

¹⁸ *Prosopis* unambiguous identification is possible due to the irregular starch grains in this species, whilst redundancy with maize is due to the regular starch grains

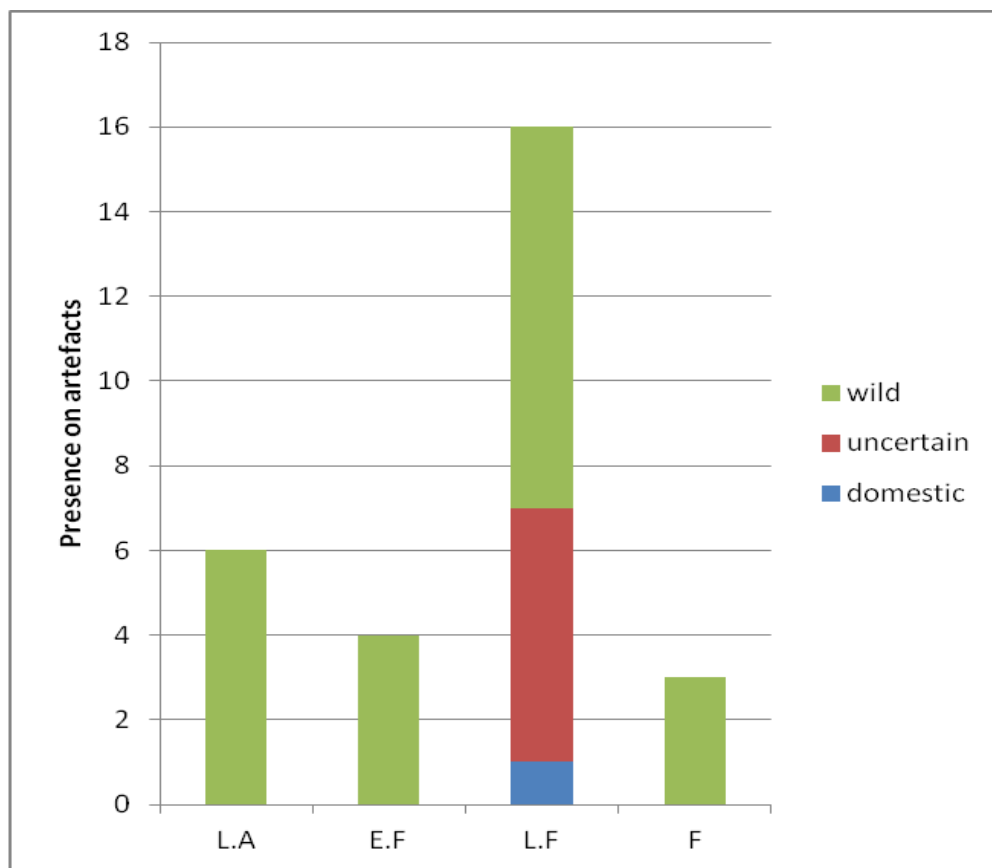


Figure 111. Category and taxa of plants on grinding tools in L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).

It is not possible to correlate specific species with the morphology of the mortars, as *manos* with different and sometimes with multiple morphologies provided a large number of the samples (Figure 112).

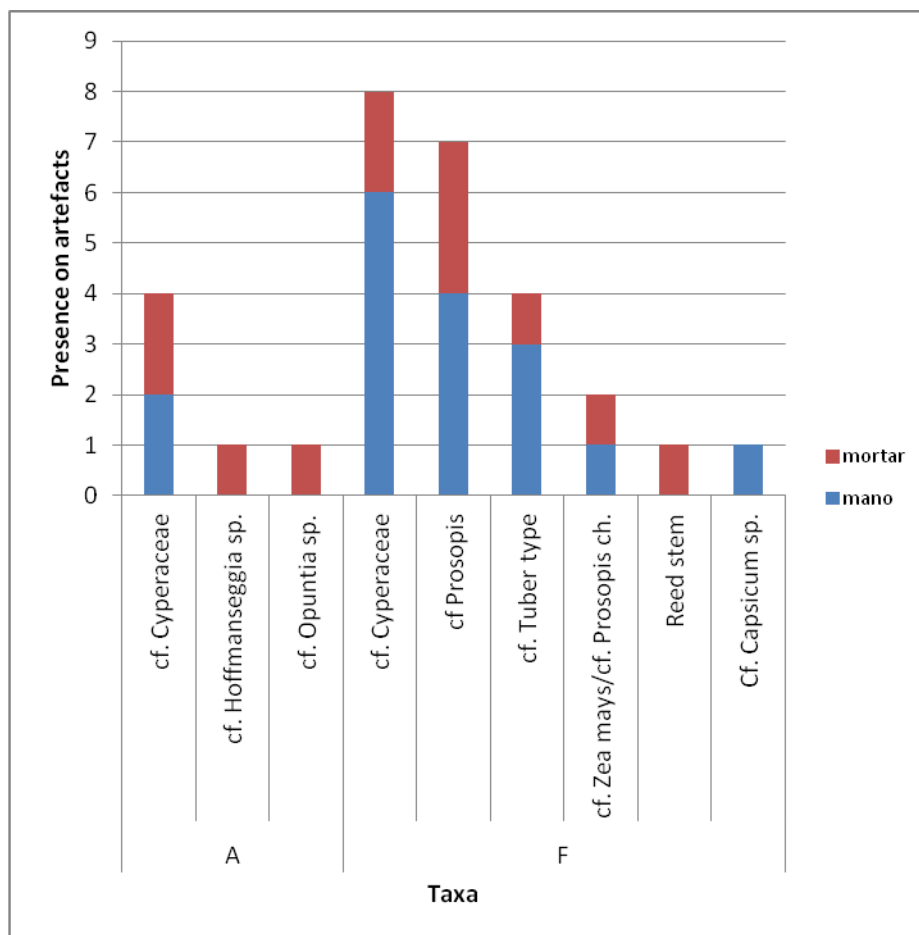


Figure 112. Presence of taxa on *manos* and mortars during the Late Archaic (A) and Formative (F).

However, all the Late Archaic mortars and some of the Formative mortars, as in Tulan 85, are conical, though the flat model is predominant in Early Formative sites (Tulan 54, Tulo 1) and becomes more dominant through the Formative period and later on (Carrasco 2003). The continuity of species through time suggests that there is no relationship between change in form and resources processed. Numerous authors agree that forms are not exclusively correlated to certain resources (Adams 1993; 1999; Liu *et al.* 2011; Wright 1994). In this sense, flat mortars are related to grinding, whilst conical mortars are more related to pounding, actions which affect the size of the particles obtained, and this is linked to the preparations of different foods and their nutritional values (Wright 1994). Flat mortars have been reported by several authors as more efficient than conical, as the wider surface allows less time-consuming work for the same amount of product processed (Adams 1993; Babot & Bru de Labanda 2005; Mauldin 1993; Wright 1994). Flat surfaces have been proposed as implying less effort to use and that the fine ground powder has greater bio-accessibility and storability (Babot 2004; Jackson & Benavente 2010; Stahl 1989; Wollstonecroft *et al.* 2008;

Wright, K. 1993; Wright 1994). So, their adoption during the Early Formative could be implying different food preparations such as potential *chicha* maize in Tulan 54 (McRostie 2007), or other *chicha* plants (e.g. *Prosopis*) and also could be because of the lower effort of grinding (Babot 2004; Latcham 1936b) as well as the intensification of production or productivity.

The predominant residue found in Archaic samples is made up of *Scirpus* -Cyperaceae- tubers. Species from the similar genus *Bolboschoenus maritimus* (syn. *Scirpus maritimus*) required “Pulverising as a necessary step in transforming these tubers into edible products because it disrupts the cell walls, facilitating tissue softening and access to intracellular nutrients” (Wollstonecroft *et al.* 2008, 19). Processing of *Scirpus* tubers might have been hard work (Wollstonecroft & Erkal 2003), though the high kilocalories as well as the reduced effort in collecting them in terms of movement from the residential base and their permanent presence in the river and ravines made them the preferred wild plant until the Early Formative period (Figure 113).

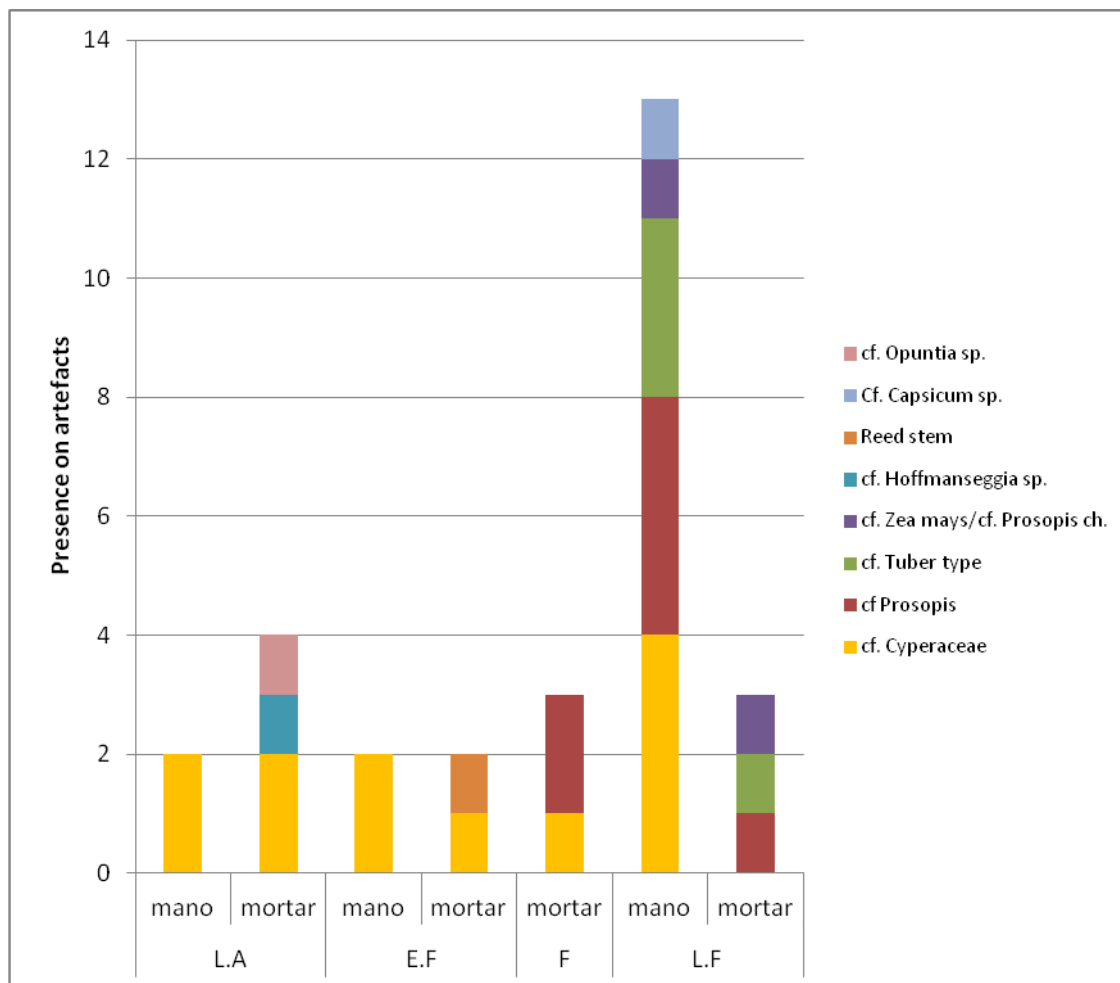


Figure 113. Taxa on grinding tools by time and sites. L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).

Sedge tubers can be de-husked in conical mortars. If the base is flat, it is more likely to be used for grinding, though in the case of sedge stems, they could be placed on a flat slab to remove the pith either with the aim of consumption or to use the stems in crafts such as basketry, or both together (M. Wollstonecroft pers. comm. 2013).

Other tuber types, though of uncertain identification, permit some statements regarding grinding methods. Some potatoes “were an unpredictable and dangerous resource until some way was found to eliminate their potential toxicity” (Johns 1989, 513). Stahl (1989, 172) states that grinding/pounding/grating can be a step towards detoxification or the separation of desirable from undesirable, and in this sense, fibres in tubers might be undesirable for several nutritional reasons. Detoxification of bitter potatoes by modern Andeans is by a labour-intense leaching and freeze-drying process (Johns 1989, 513) and the

reduction in size of particles increases the efficiency of detoxification procedures such as leaching (Stahl 1989, 174). Some *Solanum* varieties require pounding and sun exposure before they can be consumed; in addition, the common potatoes can be ground and made more palatable after being preserved as *chuño* or *tunta*. Other tubers like oca or achira can be stored after dehydration and then ground (Babot 2004, 199). So maybe grinding might be more necessary once these products are dried and then need to be transformed into some meal.

As I discussed previously (question 1), an intriguing finding which confirms previous macro-remains is the significant lack of legume fruits in Archaic sites. So could be that the cultivation of *Prosopis* during the Formative influenced changes in processing techniques, but if they were native to the oases, then it might be that the cost of pounding these resources was not considered necessary when the pods could be eaten raw (Villagrán *et al.* 1998a; Villagrán *et al.* 1998b). Considering the energetic costs of processing, *Prosopis* pods release fewer kilocalories after being ground in flat rather than conical mortars, but more when not ground at all (Llano & Ugan 2009), although once the oases start acquiring more relevance in the settlement patterns of the Formative communities, these costs could be compensated by the immediate access to these resources and a reduced mobility strategy. As Wright (1994) proposed for the farming transition in the Levant, an increasing presence of grinding tools (and diminishing of pounding tools) could be an attempt to “maximise nutritional returns of plants harvested from the limited territories characteristic of sedentary foraging and early farming” (Wright 1994, 238). Also the presence of flat mortars could have diminished the effort needed to grind, and hence increased the amount processed either for interchange or consumption. During the last phases of the Formative period, increasing interaction, social networks or trading have been proposed as an important trigger in the intensification of these trees (Agüero & Uribe 2011; Agüero *et al.* 2009; Vidal 2007). Hence their preparation as flour or *chicha* might have played an important role in social gatherings, but also as an exchange product with the highland and tras-andean populations, by whom, until historic times, these products were highly appreciated (Núñez 1993). Flour reduction allows a reduction in the weight and volume of the product, making it more suitable for transportation (Barrows 1900). Barrows reports

that for the Coahuilla Indians of southern California, the ground pods “were sometimes rolled into compact balls and carried for food on a journey” (Barrows 1900, 56). For the area, the preparation of *patay* could be an analogy for the compact balls mentioned by Barrows.

Summarising my conclusions for this third question

Flat mortars probably came to the area as an introduction during the Formative period. This new morphology is not correlated with crops but with a prevalence of wild plants such as Cyperaceae as well as the processing of other species such as *Prosopis* and/or tuber types. However, other potential resources that could have been prepared on them should also be considered, such as animal (e.g. *charqui*) or mineral (e.g. beads). Nevertheless, more than any specific resource, the morphological change was probably related to other variables, such as reduced effort in processing, and therefore it could provide an avenue for intensification within a risk-spreading context. This intensification could be done in terms of better bio-accessibility, new recipes suitable to strengthen social networks or more productivity and/or production, though by the end of the Formative period, their use could be more related to social demands and food pressures. Hence it reflects an altered engagement with different resources and the possibilities to prepare or process them in different ways. Whatever the initial reasons why communities shift from conical mortars to flat, this shift seems to represent an advantage, as it has prevailed through time and displaced conical mortars almost entirely.

4. Why were previous occupation sites in the ravines abandoned and new permanent settlements in the oases established during the Formative period? Is this related to the onset of plant production?

Due to the lack of evidence for maize production and uncertain evidence of some tuber horticulture, it seems that these cannot be used as an explanation for the colonisation of the oases during the Formative period. An intensification of trading related to a demand for forests resources may be significant by the Late Formative (Agüero 2005; Agüero & Uribe 2011; Vidal 2007), but this does not explain the initial movement to the oases at the beginning of the Formative. On one hand, why did humans decide to start using these

resources, whose nutritive characteristics are outstanding while their availability and gathering costs are minimal, only at this particular point in time? On the other hand, if they were initially cultivated during this period, this in part could explain the movement to this lowland area, whose landscape would become increasingly domesticated and populated¹⁹.

However, acknowledging a risk-spreading perspective, I do not think this should be described as a main driver for settling in the oases. I believe one main bias in interpreting Formative changes to settlement patterns has been the over-emphasis on the role of plants in the economy and the dichotomization between animal and plant economy. Hence I do not think Formative people shift entirely their subsistence patterns and therefore I want to re-evaluate the predominant role of the camelid for the Atacama people:

“This explains why we feel the necessity to study the whole system of livestock in the Antofagasta region. Is it useful to acknowledge that whilst all the other activities of men such as mining and agriculture have come and gone through time, herding is a principle way of life and continues to be a fundamental activity for Atacama communities” (Serracino & Stehberg 1975, 74) (translated by V. McRostie).

I think that domestication of camelids brought the possibility to move with them into other niches beyond their original wild habitats, encouraging the movement to the oases. Even if hunter-gatherers could exploit wild camelids in the lower belts, as is shown in the Archaic site Tambillo (Núñez & Santoro 1988), this pattern seems not to be optimal and the authors have related it to environmental stress (Núñez & Santoro 1988). When comparing the density of camelid bones in three Archaic sites (Tambillo, Puripica 1 and Tulan 52), we can see that Tambillo 1 settled in the oases has the lowest density in comparison with the other sites located in the ravines (Table 50).

¹⁹ This preliminary hypothesis still requires further comparison

<i>Site</i>	<i>Ecosystem</i>	<i>n grids m₂</i>	<i>Camelid bones</i>	<i>Density (n/m₂)</i>
<i>Tulan 52</i>	<i>Ravine</i>	28	12096	432.00
<i>Puripica 1</i>	<i>Ravine</i>	27	3426	126.89
<i>Tambillo</i>	<i>Oases/salar</i>	42	1047	24.93

Table 50. Density of camelid bones in three Archaic sites. Adapted from (Núñez & Santoro 1988, 58).

Also it could be that Archaic campsites in the oases have not been found yet, though recent surveys have only identified a few ephemeral Late Archaic occupations located in the San Pedro oases, which do not reflect intense hunting and slaughter activities (Agüero & Uribe 2011) and therefore are more likely to be related to seasonal foraging²⁰. Hence the Archaic settlement pattern responds to a strategic position in the middle altitudes, which allowed better access to a seasonal hunting/herding of camelids and other fauna as well as to wild plant production in the upper and lower altitudes.

However, after the domestication of camelids, the colonisation of other environments could have been achieved without severe risk. The occupation of the oases could have represented an extension of previous strategies into a new environment as well as a new horizon of subsistence practices, resources and social relationships. As the archaeobotanical analysis for the Formative has provided little evidence of intense agriculture, there is no reason to assume that agricultural production played a fundamental role in the colonisation of the oases of San Pedro. The presence of spherulites rather than crop microfossils on hoes from the oases sites reinforces the role that herding might have had in the colonisation of this ecosystem. In this regard the management of camelids within this environment could allow the beginning of silvicultural (and silvopastoralists) practices prior to the emergence of subsistence based on the annual cropping of agriculture crops. Agriculture is usually assumed to precede arboriculture, partly because it is thought that sedentary agriculture

²⁰ The fact that the season of fructification of Leguminosae trees at the oases (at least three months) is when the higher productivity is occurring in the upper belts (Núñez 1995) could imply that the gathering and consumption of these pods was made in an expeditive way, rather than establishing campsites and more curate technology in the oases. However, this use of space and resources depends on whether these trees were available in abundance previous to the Formative period.

would provide the necessary conditions for the cultivation of trees which have a longer life cycles (Hughes *et al.* 2007; Zohary & Hopf 1988). However Smith (1967) reports contemporaneous early tree cultivation with herbaceous crops in Tehuacan valley. In the oases herding practices would provide an alternative subsistence base that could be as important as plant food production. In previous work this has been dismissed for several reasons, possibly reinforced by current practices in the area, which have strengthened the assumption that maize must have been the most important crop since early times.

During the Formative period, Agüero (2005) proposes an initial, more mobile and intermittent occupation of the oases, which stabilises towards the Late Formative, though she links this occupation to gathering and horticulture rather than to herding (Agüero 2005, 51). She states that the lack of evidence of caravanning in the oases in later periods is evidence that herding activities were not performed in these lower belts. Also, Núñez (1995; 2005) proposes the absence of herders in the Tilomonte oases during the Formative period due to his assumption that llamas do not breed well at these altitudes. Another reason given by Núñez (1986-1987) to migrate to higher zones is the presence of mosquitoes (*jerjele*) in the lower oases. However, beyond the Atacama several authors have documented a good adaptation of camelids to lower altitudes (Cadwallader *et al.* 2012; Finucane *et al.* 2006; Shimada & Shimada 1985; Wheeler 1995). “While popular mythology holds that alpaca and llamas do not adapt well to the middle and lower zones, Flores Ochoa (1982) has argued convincingly that at one time they flourished at lower altitudes” cited in (Guillet 1987, 88). For instance, Shimada and Shimada (1985) argue that there is good evidence for the breeding and herding of llamas and even alpacas during the Early Horizon in coastal Peru. Locally, Tulan 85 is an example of herding management at these altitudes, although Núñez (1995) assumes this was a response to “environmental stress”. But, in Tulor 1 there is strong evidence for camelid exploitation (Barón 1986; Llagostera *et al.* 1984) and corrals with layers of dung (Barón 1986). Although identification of these camelids to a species level have not been done, Barón (1986) states that in the corrals, the bones found were bigger than in the village, and hence this could be related to differences in animals to use as food versus transportation. Llagostera *et al.* (1984) state that camelids were sacrificed as young adults, although some of them suggest newborns or very young individuals. The presence of

newborns in abundance has been used as an indicator of herding, as of the number of newborn is likely to be higher in corrals than would be found in most natural settings (Cartajena pers. comm. 2013). Hence, the Formative sites located near riverbeds and seasonal water floods could be seen as providing areas of greener pasture suitable for camelids to graze near the campsites (Llagostera *et al.* 1984) where livestock could be maintained for products (meat, wool and dung/fuel) and for transportation. Shimada and Shimada (1985, 22-23) propose that the maintenance of camelids by the coast “may have involved various strategies: grazing in algarrobo forests, lush side valleys, canal and riverbank vegetation, and harvested fields and feeding in corrals”. In northern Chile, “different strategies might have extended the size of bofedales or meadows using irrigation canals and low walls (*champa*) or burn areas to encourage the growth of tender shoots of vegetation” (Dransart 2002, 39). Langlie (2011, 45), mentions that the totora could have been cultivated as camelid fodder during the Bolivian Formative. Indeed, Olivera (1998) suggests that early horticultural labour was related to growing and processing plants for animal feed rather than crops for people.

So, if we reconsider this possibility that herding rather than agriculture was the main subsistence activity, it is also necessary to reevaluate the assumption that Tulo was the hallmark of sedentism during the Formative period (Barón 1986; Llagostera *et al.* 1984; Núñez 1989; 2005). In economies where domestic camelids are a major component, the pattern of mobility should be carefully analysed, considering the local ecologies and available resources (Olivera 1998). In the case of pastoralists, social relationships of ownership are not concerned with immobile property such as land, but with movable property in the form of camelid herds (Dransart 2002, 198). Dransart (2002) has already questioned the agrarian and sedentary status of Tulo. She proposed that Tulo 1 was seasonally occupied by pastoralists and that hunting and gathering activities continued to be practised into the Formative period and beyond (Dransart 1991; 2002). However, she uses as evidence of seasonality the one-metre sand layer between the original village (Tulo I phase) and the later cemetery (Tulo II phase), which actually represent different chronological phases of occupation. What I think could reflect a seasonal occupation of Tulo are the fine grooves of eolic sand deposition in the lowest layer of the lower horizon

(10-30cms) of the Tulo I occupation, in which the original village was settled (400BC-100AD) (Llagostera *et al.* 1984, 106). Also, the cellular growth of the village related to a functional readjustment during its lifetime and the gradual hierarchisation of the system (Adán & Urbina 2007; Llagostera *et al.* 1984) could be related to seasonal occupations. And the seasonal more than permanent occupation of the village could explain why there are almost 500 years contained in just 10 to 30 cms of soil.

This camelid or herding predominance might also explain the non-structured and non-dense habitation campsites recorded in the oases during the Formative period (Agüero 2005; Llagostera & Costa 1999; Núñez 2005). Seasonal mobility could persist until the Late Formative, being coherent with a pastoral way of life, which relies on available grasslands and seasonal resources. Whether this settlement pattern reflects transhumant movements or double residence in pattern and thus whether Tulo 1 is a permanent or a semi-permanent site requires a wider consideration of other important aspects of these Formative societies, such as fission/fusion strategies, division of labour and gender relations (Kelly 1992). Numerous names and definitions have been given to the way in which Atacama peoples used their territory (e.g. Hidalgo 1985; Martínez 1998; Núñez 1981b). Núñez (1986-1987) describes the settlement pattern of a couple of herders from Peine. They never stay for too long in one place. They have pasture land stretching from the oases to the highlands which they use to follow a transhumant movement. "During the winter months from May to August, they remained below altitudes of 3000masl, moving to higher grounds in September or October. They stayed at high-altitude places of residence in November and December, returning to lower altitudes sometime between January and April, depending on the weather conditions. When moving from one pasture ground to another, the herders followed the Tulan stream and they spent the night in rock shelters surrounded by dry-stone walling that divides the shelter for the human beings from the adjacent corrals for the animals". Serracino and Stehberg (1975, 75) describe herding life in Guatín, where there is a residential base from which the herder moves on a daily or temporary basis. Villagran and Castro (1997) state that llamas are left in different environmental belts with available forage, and after three or more days, herders go to look after them: hence, the predictable and gregarious ethology of camelids could have provided some flexibility to allow people to

occupy a range of environments. Therefore, it might be that we are only able to see some sites of this larger system. Núñez *et al.* (2006) refer to the settlement pattern of early herding societies as “sedentarismo dinámico” Olivera (1998, 165), being a year-round residential base, often settled in fertile niches, from which part of the group would move seasonally to different ecological zones. The time and periodicity of these movements depends on the type of resources they want to obtain and if they have direct or indirect access to them. As Núñez (2005) argues, it might be that the oases was becoming an important geographical centre in which rituals and cemeteries were established and hence it seems a main turning point in the previous settlement pattern is occurring through the Formative period, gradually establishing the precedents of what would be the main core of social life in the oases during the Middle period.

Summarising my conclusions for this fourth question

Hence I think domestication of camelids was the trigger that allowed the movement to lower belts and the colonisation of the whole altitudinal transect. Rather than an abandonment of previous ecosystems, this can be seen as a more diversified use of space as part of a risk-spreading strategy. This complementary use of space is well recorded in the ravines (e.g. Agüero 2005; Núñez 2005, amongst others). With the initial movement to the oases, they could have started the management of forest resources, allowing them to diversify and intensify their economies, as previously discussed, together with more optimal areas to permit larger and more sedentary settlements through time (Núñez 1989) and the formation of a space suitable to receive and carry out trading and social operations (Agüero & Uribe 2011; Llagostera 1996). Early herders applied logistical strategies that allowed them to occupy different niches seasonally: how these movements were performed should be analysed case by case, but the scattered use of space within a broad-spectrum diet was highly desirable in the puna environment. Therefore, creation of some more permanent settlements would not necessarily undermine the high degree of seasonal mobility associated with the pastoralism of these groups (Olivera 2001, 2).

For the Loa area, it seems that a greater reliance on the oases was also facilitated by herding/foraging strategies and only later did this develop into a dependence on agriculture (Benavente 1988-1989; Mena 1984; Pollard 1971; Pollard & Drew 1975).

5. Is it possible to identify whether these changes are autochthonous or whether they relate to new populations moving into the area?

Since there are different hypotheses about identities interacting in the area (especially in the Salar de Atacama) during the Formative period, I will try to consider some of these arguments in the light of the revised data we now have about food production and consumption, given that food is intimately linked to identity and hence can be understood as embodied culture (Atalay & Hastorf 2006; Bourdieu 1984). I must acknowledge that this interpretation is more speculative than previous discussions, as it relates to multivariate processes and communities that could have been interacting and involved in the Formative period of Atacama, as well as the multiple material and immaterial supports that could have been used to express it consciously or unconsciously. Yet the new data does contribute some advances towards the exploration of this subject.

Regarding isotope data, I do not have values for the Late Archaic period. The sites sampled for the Formative period do not reflect differences in their means except for the site of Chorrillos, which includes individuals with values that seem to be lower in the whole and protein diet (Figure 114). This could reflect differentiation in their foodways, such as consuming non-C4 pseudocereals, as some specimens of Chenopodiaceae found in the tombs allow me to suggest (Belmar & Quiroz 2005), or not consuming cactus even though they could be available in the area (Kattermann 2011), or maize, which is not present in this site (Belmar & Quiroz 2005) but is present nearby in Topater cemetery (Thomas *et al.* 1995); and they consumed other types of fauna less enriched in C4 plants. But it could also be that this does not represent a cultural choice and/or a difference with inland populations, but just a matter of ecologies in which camelids or herbivores are grazing plants less enriched in C4, and therefore collagen values are lower here even though the diet is not changing in terms of its main ingredients.

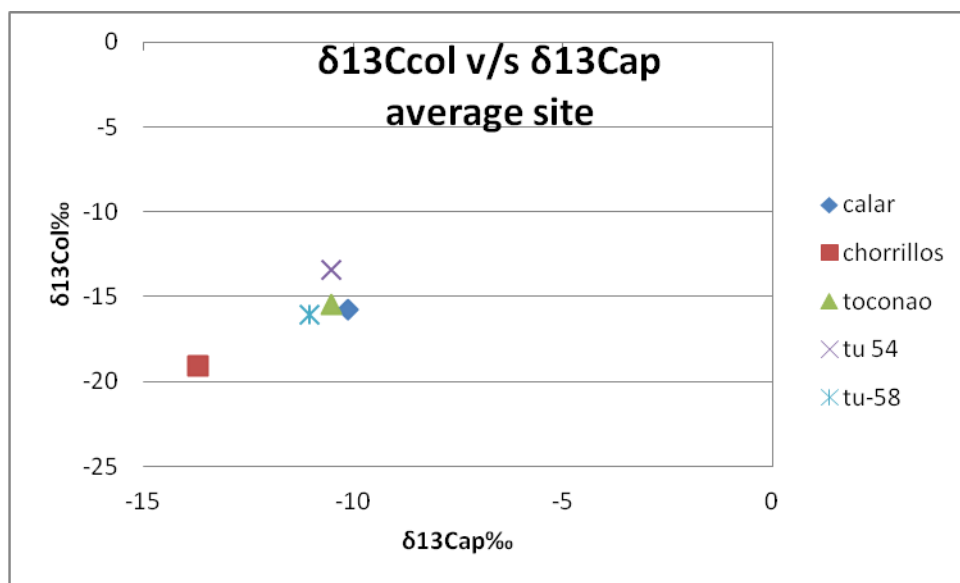


Figure 114. δ13C mean values for sites.

Internal variability of individuals within sites (Figure 115) is hard to interpret due to the small size of the sample, but this could signal some of the mobility and interchange during the Formative period, as suggested by researchers (Barón 1986; Benavente 1988-1989; Llagostera *et al.* 1984; Tarragó 1989) and the bias that might exist in newborn individuals sampled from Tulan 54.

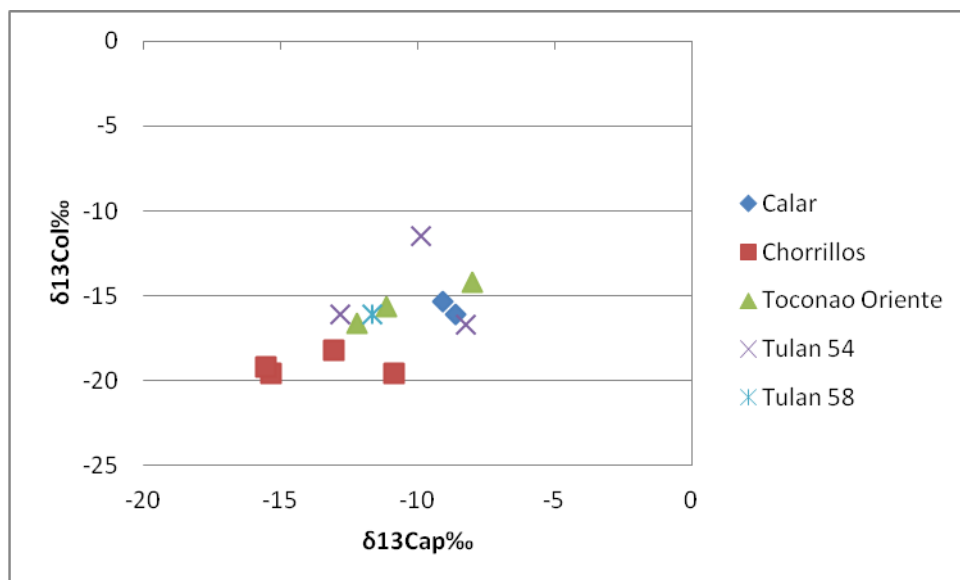


Figure 115. δ13C values by individual in sites.

Neither the Oxygen nor Strontium values indicate strong signs of mobility, although I acknowledge the methodological problems (Knudson 2009) and the sample size is just preliminary and not conclusive. Strontium shows that just one individual from Tulan 58 might have lived in the Bolivian Highlands, at least during his infancy, whilst the others are within the range of San Pedro de Atacama. Oxygen reveals a slight difference in the mean of Chorrillos, which is lower than inland sites and might be reflecting the consumption of underground waters rather than superficial streams. Also when analyzing the range of these individuals, some of them have the same values as inland sites.

Using microfossil results and previous archaeobotanical data, it seems that Late Archaic populations through the area are exploiting similar plants, such as Cyperaceae, Cactaceae and tubers, which grow in ravine ecosystems. Hence, the archaeobotanical findings match with the previous categorisation of a Late Archaic tradition known as the Chiu Chiu complex or Tulan–Puripica.

From what has been discussed so far, I do not see a major disruption between Late Archaic, Early Formative and Late Formative communities. There is continuity in the use of some foods, such as Cyperaceae, *Opuntia* and tubers, although the appearance of new plants such as *Prosopis* and some crops, as well as the increase and diversification of tuber types, could be taken as a slight shift in foodways, but these do not reflect a radically new intrusive tradition. First of all, it is likely that camelid herding communities are the ones that colonise the oases; second, the appearance of *Prosopis* or tubers is found alongside continuity in the use of the earlier resources. Third, there is a common pattern for the whole of the area throughout the Formative and Late Archaic, in which sites at ravines and oases exploit mainly nearby resources but also present cross-presence between them, and thus suggest a complementary use of space (Figure 116), and fourth, the lack of significant quantity of crop remains advocates the continuity of local communities rather than the migration of farmers.

Formative communities of Atacama largely represent a development from Late Archaic practices, with a strong continuity in many aspects of food collection and processing suggesting that food played a role in cultural reproduction and identity maintenance as well as a risk-spreading subsistence strategy. So, from preliminary results from the isotopes and

archaeobotanical analyses, it seems that Atacama populations are preserving and sharing similar patterns of foodways and this suggests continuity of the population through time and space.

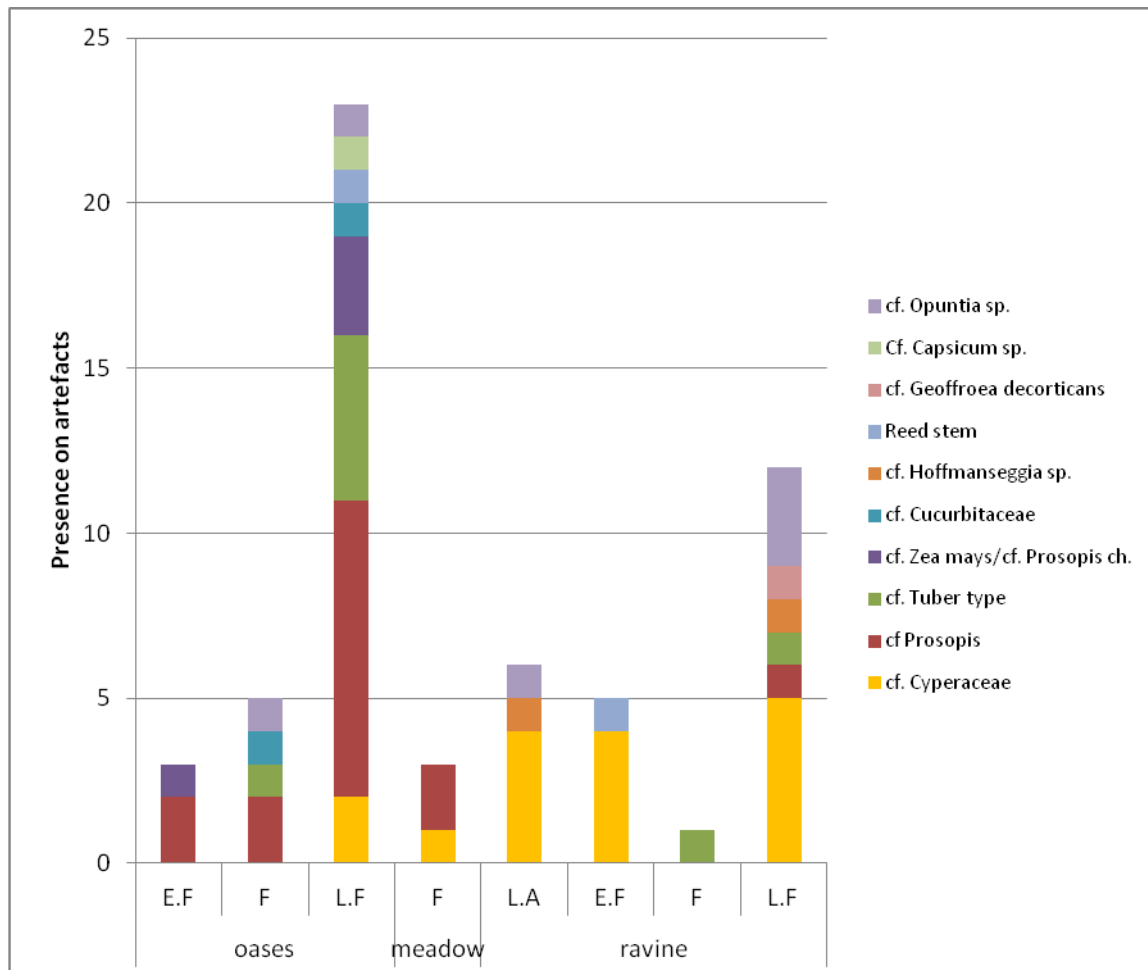


Figure 116. Taxa in sites regarding their locality and period L.A: Late Archaic; E.F: Early Formative; L.F: Late Formative and F: Formative (represents all the Formative sub-periods).

Moving to a wider scale of comparison, it seems that even if the Atacamenos are incorporating new resources, they are selecting a restricted range and not choosing/accessing all of the available crops circulating during this period in neighbouring areas (e.g. the northern Chilean Coast- see CH. IV). Also, there is a particular pattern similar to other Formative highland contexts of the Atacama Puna in which herding, hunting, gathering of seeds and tubers played the main role and horticulture or agriculture played a lesser role (Babot 2006; Muscio 1999; Olivera 1998; 2001; Pintar 2008; Rodríguez & Aschero 2007). Martínez (1998) proposed gathering rather than agriculture as the subsistence

strategy that characterises these groups, and within this strategy, the management of forest resources together with camelids could be an element of differentiation from other highland and coastal or trans-Andean populations. Hence, the hypothesis of the Algarrobo Complex (Martínez 1998) for the Western Atacama populations could be plausible, at least during the Formative period, when these resources seem to gain relevance and crops production still seems to be a minor complement.

However, these generalisations should not deny the diversity found during the Formative period. Different types of social networks and complementarity were leading to multi-cultural interaction and this is evident in other cultural materials (Stovel 2008). The arrival of new tools (hoes, grinding stones, pottery) and crops could be related to these dynamics.

Summarising my conclusions for this fifth question

Continuity in the subsistence strategies regarding plant and animal use are seen through time and between the different ecosystems. Hence I am more inclined to propose that rather than a migration of farmers, or a separation between oases and ravine peoples, the societies involved in the Formative changes are all part of a single tradition that is adapting to new environments with more permanent occupation alongside seasonal transhumance and diversifying their possibilities through exploitation of different ecological levels. In this sense, their subsistence strategies and resource use linked them to a Highland tradition in which resources such as different types of tubers and camelids are relevant, though the reliance on Legume forests allows us to differentiate them from other highland communities (e.g. Wankarani, Chiripa) and compare them with coastal populations between the Loa and Camiña rivers and other societies which actively use these trees (e.g. in Coastal Peru or Northwestern Argentina).

IX.2 An alternative model for the western slope of the Atacama Puna Atacama and Formative human-plant interactions

By narrowing the previous gaps and re-evaluating the role and definition of wild and domestic plants, as well as the function of artefacts related to them, I contest previous hypotheses and explanations regarding the changes to settlement patterns and functionality of technology that assumed either an influx of external agriculturalists or the adoption of crops by local populations. This leads me to wider insights about the on-going continuities in the cultural and social dynamics of the Atacama. Here I resume my interpretation as an alternative model for the changes seen during the Formative period and how they relate to the wider process from foragers to farmers.

Formative changes in Atacama

In relation to my first objective, which was an understanding of subsistence and cultural changes during the Formative period, I conclude that they were not related to the adoption of agriculture or a major change in the production of traditional crops. A wider conceptualisation of the Formative period requires a consideration of many kinds of food production and not exclusively agriculture. Olivera (2001) defines Formative societies as having one productive component (agriculture and/or herding) related to a higher level of sedentism and particular technologies (e.g. pottery). In Atacama, Late Archaic complex hunter-gatherers established the structural changes in subsistence and social patterns with the domestication of camelids, semi-permanent settlements and increasing connectivity within and between cultural groups (Núñez *et al.* 2006). Early Formative communities relied on this traditional system, while incorporating new technologies and ideologies for which the local or foreign origin can still be debated. Hence the final stages of the Archaic and early stages of the Formative period have recently been characterised as herding-foraging communities within which agriculture did not have a main role (Agüero & Uribe 2011; Agüero *et al.* 2009; McRostie 2007; Núñez *et al.* 2009; Vidal 2007). However, and as some authors have already asked, why would these well-adapted and successful herding societies settled in the ravines abandon their lifestyles towards the end of the Early Formative?

Pressure models such as environmental constraints, demographic growth or social competition are not pertinent to explain the changes in this area during the Formative period. Without internal/external pressures, Winterhalder and Kennet (2006, 18) propose that “Foragers in positive energy balance will be risk averse”. However, the colonisation of a different belt by these herders did not mean a survival threat because several risk-spreading strategies were taking place, such as scattered occupation and mobile lifestyle; diversification of economy with primary and secondary products obtained from plants and animals; enhancement of carrying capacity with new technologies and a strengthening of social networks, as multiple records show.

As I see it, in the Salar de Atacama area, the Formative populations had gained control of their camelid herds and were able to take the risk of abandoning the ravines to more fully occupy the oases, precisely because now they could move with their main resource – the camelids – and provide them with pasture (grasses, shrubs and forests) by manipulating water resources and different types of vegetation. This movement allowed them to establish occupation in wider patches and take advantage of diverse resources more efficiently. They could broaden their diet spectrum in just one place, while still maintaining use of their previous sites or territories (Agüero 2005; Agüero & Uribe 2011; Agüero *et al.* 2009) where not just resources but also memories and gods remained.

I am not denying that upper belts were the optimal habitat for herders, but evidence points to mobile and small herds also utilising the oases during the Formative period. As a result, herding rather than agriculture in the oases could explain the lack, or ephemeral presence, of habitation sites during the Formative period (e.g. Tulor 1, Coyo Aldea); as well as their location in San Pedro riverbeds. Tulor 1, used as the archetype of the first horticultural/agricultural village in the area, can be re-evaluated as a herding semi-permanent village. The fact that nearby resources are used in all of the sites implies a reduced mobility, as has previously been acknowledged, though the character of this sedentism need to be further explored to understand social strategies and their implications.

Thus, I agree with Núñez (2005) that the oases’ occupation was part of a spread in space by the same populations rather than by a new population with different identities; though

contrary to him and coinciding with Agüero and colleagues (Agüero & Uribe 2011; Agüero *et al.* 2009), the data presented in this thesis confirms that the increasing complexity seen in the oases of San Pedro was not sustained by a significant level of crop production. However, and now taking a distance from the latter authors and recalling the possibility of camelid herds in the oases (Barón 1986; Dransart 2002; Llagostera *et al.* 1984), I do not think that there is a separation between hunters/herders in the ravines and horticulturers/gatherers in the oases; but instead there is a fusion of both activities in one place, supported always by a scattered use of space and social networks.

If *Prosopis* forests had been available since the Early Holocene period, then I doubt that the Atacama populations would have waited till the Formative period to decide to use these nutritious beans more intensively. I have already discussed the predictability, nutritional, and other outstanding characteristics of these trees, as well as their importance in the present and in several pre-Columbian and historical populations; hence, their absence during the Middle and start of the Late Holocene followed by their increasing presence through the Late Formative leads me to reconsider their wild status and opens new horizons to explore either a cultivated or a promoted/managed landscape for the oases (Clement 1999). In this sense, the excessive attention to traditional crops (e.g. maize, Cucurbitaceae) has undermined the relevance of non-traditional local cultivars and therefore obscures a whole series of subsistence practices and management of resources.

Hence the possibility to manage animals and plants in one place allowed an increasing stability through time, attracting transit populations and the development of trading, as multicultural contexts suggest, leading Llagostera (1996) to propose a reticular model in which San Pedro oases become a *pier polite* around 700AD. It is within this active trading that Agüero and Uribe (2011) and Vidal (2007) propose *Prosopis* products as an important local resource by the Late Formative. This major stability also relied on storable resources such as tubers, or year-round Cyperaceae tubers, and on new technologies such as pottery, metallurgy, textiles, flat mortars and hoes, among others. In this context, I think flat mortars allowed an intensification of plant processing through more efficient processing, and increased bio-accessibility as well as the possibility of new consumption patterns, either by storage or exchange. Intensification was also possible by reducing searching costs (e.g.

through the location of *Prosopis* and other plants as well as the camelids in the same area). However, the introduction of this new model of grinding tool during the Early Formative might also have been related to variables such as new recipes, cultural diffusion or reduced effort. On the other hand, the lack of crop microfossils on hoes relates them better with enhancement of productivity, such as the management and procurement of wild or semi-domesticated resources or building and cleaning activities. This same process was on-going in the Loa area, where the control of camelids in Late Archaic niches, plus other technological innovations, allowed intensification of traditional resources as well as the procurement of new foodways.

I do not take an extreme position that claims that crops were totally unimportant during the Formative period, but whether local farming was providing some crops or if these were imported; their initial small-scale introduction into social life needs to be understood within a context of continuity and gradual change rather than the trigger of fundamental changes. More than traditional domesticates, the domestication of “wild” plants should be further discussed and explored.

A comparative perspective for animal-plant-human relationships during the Formative Period

To insert and complement this model in the broader discussion of the adoption of agriculture and plant production, I refer to my second objective, which was to contribute to the debate on the “Formative” period. In particular I hope to contribute to a better understanding of the emergence of agriculture in the Andes and South America where primary data is still limited and the explanations of how, why, where and when agriculture was developed, adopted and consolidated are not well understood.

Hence, confirming previous studies, in Atacama there is a gradual process of adoption of agriculture and even if I do not know when agriculture became a main subsistence activity, it was not until around 750AD when terraces and paleohydraulic technologies multiplied in the area (Castro *et al.* 2004). In fact it is not until around 1000-1400AD, during the Late Intermediate period that more precise references for identifiable agricultural infrastructure are given (Pollard 1970; Schiappacasse *et al.* 1989). “In northern Chile the agricultural

process did not erupt violently to disrupt the hunter gatherers' societies, but it was a gradual process of adoption and adaption where the local communities balanced the primitive economy which sustain them for millennia and the one that started to be developed" (Muñoz 1989, 113), translated by V. McRostie).

The mere presence of maize during early times should not be taken as an indicator of a dependence on agriculture or horticulture. "One should not assume that the full impact of a new crop is felt immediately upon its appearance in the archaeological record" (Pearsall 2007, 84). The "maize-centric" perspective that has predominated in the Americas is largely due to the role this crop plays at present and when European contact happened (Pearsall 2007; Terrell *et al.* 2003). As several authors have shown, maize seems not to have had a major impact on the economies and subsistence of the Formative economies of the Andes, but only after a further millennium (Drennan 1996; Logan 2006; Minnis 1992; Olivera & Yacobaccio 1999; Pearsall 2007; Rivera 2005; Smith 2001b; Staller 2003; Staller & Thompson 2000; 2002). The other potential crops that could be important in Early Formative Andean communities, pseudocereals and tubers (Bruno 2001; Korstanje 2005; Langlie *et al.* 2011; Piperno *et al.* 2000; Santoro & Chacama 1982), do not permit sufficient accurate identification to confirm their significance as fully domesticated plants. Previous macro-botanical analyses have not been conclusive about the domestic status of *Chenopodium* (Belmar & Quiroz 2005; McRostie 2007; Vidal 2007) and tubers have only been reported from the identification of starch grains (McRostie 2007). The other domesticates that are circulating in the area are *Lagenaria* and probably *Capsicum*. Their abundance cannot be estimated, but the evidence presented in this thesis and previous studies have shown, it seems that they did not form a major proportion of the diet, and neither were they a main reason for technological and subsistence change.

Hence although the possibility that these societies were cultivating crops cannot be discarded it should at least be re-evaluated as these activities do not appear to have been at sufficient scale to explain the development of social complexity or to represent a fundamental subsistence change. However, from an evolutionary perspective, whether domesticates are present or not is not the main determinant of the transition from hunter-gatherers to farmers, but the process of domestication *per se* and the different practices

and methods that societies have in their relationships with wild and domesticated plants. Hence, in the Atacama, what seems to be more significant is the continuity of wild plant production or cultivation (Ford 1985; Harris 1989; 1996a; Smith 2001b). Formative societies of Atacama were located somewhere in between gathering and agriculture, or in the “middle ground”, probably as low food producers with domesticates (Smith 2001b). Different levels of management and practices might have enriched daily subsistence and domesticated the landscape, and the increasing level of human interaction and anthropogenic selection might have led to significant changes in wild plant populations in the long term. However, which plants should be considered as domesticates and which as wild is hard to determine within the scope of this research. I have already discussed the need to reconsider *Prosopis* as being partially domesticated, with a management strategy that may have gone beyond simple “gathering”. Hence, until the taxonomy of Cyperaceae, tubers and *Prosopis* in the region are better known, along with the specific growing habits and reproduction characteristics of each species, it is not possible to step into a discussion of the stages, degrees or markers of plant domestication. The complexity of this issue goes beyond the scope of this thesis but presents an interesting field for future research about domestication and feralisation, among others.

But beyond the management of particular plants, the scenario of Atacama provides the possibility to define an alternative economic system as these Formative societies start colonising the oases and begin to make more intensive use of this ecosystem. So far, agro-pastoralism prevails in all the definitions of these Formative societies and subsequent periods (Agüero & Uribe 2011; Barón 1986; Benavente 1982; Núñez 2005; Núñez *et al.* 2009). A re-evaluation of agro-pastoralism has been made recently by Agüero and colleagues when they assess the relevance of gathering forest resources within the oases: hence, this could be defined as “agro-silviculture”. But in both perspectives, agriculture is linked to crop production, relegating herding mainly to higher altitudes. Therefore, the exploitation of these forests has been linked mainly to human consumption, and even if sometimes it is possible to find references to the excellent foraging properties of *Prosopis* or the word “silvo-agro-pecuarios” or agro-forestry (e.g. Gundermann & González 1995;

Llagostera *et al.* 1984), these are used as a way to denote that besides the importance of agriculture and herding, forests were also important for local economies.

Shimada and Shimada (1985) have been very clear about the plastic adaptation of llamas to different environments and diets as well as the role of *Prosopis* forests in herding. “Another possible area of prehistoric herding was the extensive thorny forest of the central La Leche, which was apparently never cultivated in prehistoric times and today still covers some 100 km square...The principal vegetation is algarrobo and today the forest is used for thriving herds of goats, sheep, pigs, and cattle” (Shimada & Shimada 1985, 20). The tremendous impact that European colonisation has had in pre-Columbian economies has been widely described for the Atacama (e.g. Gundermann & González 1995; Marquet *et al.* 1998) and implied a quick replacement of indigenous resources. As Shimada and Shimada (1985, 21) show, the rapid extinction of coastal llamas (around 1600AD) was largely due to Europeans’ predilection for their own domestic animals, particularly the pig, as well as plagues and internal wars. Also Rostworowski (1981) describes the rapid displacement of coastal camelid herds by European domesticated animals, which quickly adapted to the chaparral and algarrobo forests of the Peruvian Coast. “In the Atacama oases until today llama herds can be found in different ayllus, although donkeys, mules, ovines, goats, bovines and pigs as well as chickens and rabbits end up joining in the corrals with cuyes of pre-Columbian ancestry...” (Gundermann & González 1995, 85) (translated by V. McRostie). Boman (1908, 714) mentions that in Atacama, the maintenance of llama herds was based on algarrobo pods and *ichu*. However, the role of muleteers and introduction of alfalfa as a forage crop around the XVI century had an enormous influence on rural subsistence strategies, and currently alfalfa is one of the main crops in the oases.

During the Formative period, agricultural by-products (such as husks and stems of maize) would not have been widely available to be used as fodder, and given that Middle Formative peoples colonise the oases with their herds, at least seasonally or to maintain residential or peripheral sites, and given the fact that this is the period when *Prosopis* starts to be more ubiquitous; then it is necessary to consider that a cultivation or management of the forests could be related to herding practices and therefore the possibility of a SILVOPASTORAL system should be further explored. “Silvo-pastoralism represents an alternative production

system that integrates tree production with livestock trying to take advantage of the synergy between them with beneficial effects for the environment, economy, and society” (Ferreira De Mattos 2006, ¶ 6). These systems have been of “enormous importance in achieving sustainable and diversified production on marginal lands, especially important in arid and semiarid zones, slopes, and low fertility soils” (Ormazábal 1991, 208). *Prosopis* are ideal trees in silvopastoral systems of arid environments (Córdoba N.D.). Moreover, the plantations of *Prosopis* in the Pampa del Tamarugal have shown the “ecosystemic services of these trees in terms of silvopastoralism, wild life reproduction and recreational activities” (Ormazábal 1991, 212). In this sense, oases forests might have been more available year-round than highlands pastures, which usually increase only after summer rains, but during winter these are scarce and mostly located at an uninhabitable altitude (Núñez & Santoro 1988). Pods could have been stored for larger periods and debris and leaves of the trees could provide an extended source of forage as well as some reliance through all the seasons of the year (Silva *et al.* 2000). For Tucuman, Lafone and Quevedo (1888, cited in Arana 1999, 198) describe: “During winter they (*Prosopis*) throw away their leaves and this is useful for the beasts when grasses are lacking in the landscape”. Hence this system could have been an adaption within the original seasonal transhumance allowing people to get into lower zones than previously. This activity would have also encouraged dissemination of *Prosopis* by endozoochory if this were not spread through all the oases by this time. As well as *Prosopis*, other foraging species could have allowed herding maintenance in the oases such as meadows, with palustrian plants (*Scirpus*) and *Atriplex* shrubs, among others.

The camelid herds would have had a crucial role in fertilising these arid lands. In traditional livestock production, the combination of highland grasslands, seasonal prairies in fields, bottom of ravines, crops and local tree fruits was common (Gundermann & González 1995). Hence eventually this practice would have helped the establishment of a silvoagropastoralist system and in the long term produced fertile land suitable for more intensive agriculture. Beresford-Jones (2004) and colleagues (2011a; 2009a; 2009b; 2011b) have studied and highlighted the significance of these forests within the development of a sustainable agriculture on the riparian oases of the Samaca basin in the lower Ica Valley on the hyperarid south coast of Peru from Ocucaje Phases 3/4 of the Early Horizon (750BC)

until the Middle Horizon Epoch 2 (900AD). Therefore, the stabilising role of *Prosopis* and potential avenues for intensification of a silvoagropastoralist system in the oases of Atacama should also be explored.

This system allows the linking of both resources - herds and forests - in a relevant way that undermines the previous dichotomy made between agriculture in the oases and herding in the ravines. When *Prosopis* forests became available to support human and livestock population is still hard to define, but it might not be until around the Early Formative when these trees start to be cultivated or promoted. However, due to the scarce evidence I am not able to confirm this hypothesis. This should not be understood as a generalised and extensive practice (just as earlier models should not have been generalised as widespread agriculture based mainly on Tulo and some maize cobs). However, a silvo-pastoral perspective introduces new elements that have not been discussed before and proposes a particular case for the Formative period in the arid lands of the southern Andes.

Moving from the local context into a broader discussion of managed woodlands, Harrison (1996) provides references of arboriculture as an agricultural system in Spain and Portugal during prehistory. "In discussions of agricultural systems, tree crops usually get short shrift" (Harrison 1996, 363). Referring to *dehesas*, Smith (1987, cited in Harrison 1996, 364) describes them as "distinctive communities of plants managed by man, where animals are used to harvest the crops and convert them into dung, flesh and labour". And he proceeds, "from the pastoralist point of view a dehesa conferred far more benefits than cereal farming or irrigation agriculture. Among additional advantages were the shelter they provide for game and their longevity" (Harrison 1996, 366). In this case, trees are native to Mediterranean Europe, such as *Quercus*, which provides edible acorns. However, the high productivity and multiple uses of this tree make it in some ways analogous to *Prosopis*; and because large domestic mammals are not found during pre-Columbian times in other forest regions of the Americas, this becomes a good example to illustrate the outstanding properties that these ecosystems could provide for herders.

IX.3 Methodological and future issues

I discuss here my third objective, which was the intention to make a methodological contribution by setting up the first microfossil reference collection for the area, as well as exploring the potential of this methodology to complement research on macro-remains and re-evaluate cultural hypothesis. Here I also reflect on limitations in my own work and where future amendments could overcome the limitations and biases of my own methodology and hence define some perspectives for future research.

The microfossils obtained from the artefacts sampled present some patterns related to taxa not just through time (periods) and space (sites) but also in relation to macro-remains and general trends regarding the knowledge of wild and domesticated plants in South America during the periods studied. Moreover, they also confirm the relevance that some resources have had worldwide within different types of economies. Hence this confirms what Barton (2007, 1761) says: “there is an enormous potential for starch and residue techniques in the functional analyses of artefacts stored in museum archives”.

However, I took a conservative approach to taxonomical identifications and to the cultural attribution of the microfossils found. On one hand, the reference collection is a first attempt to explore the diversity of the microfossil world for local Atacama plants, and more accurate taxonomical distinctions for the species sampled is needed, as is more fieldwork to develop and extend the reference collection. Secondly I was unable to obtain soils from the excavated sites as control samples, made it necessary to discard multiple microfossils which I was unable to securely relate to cultural activities on the site, as they may have been introduced naturally. Also, those microfossils identified as part of cultural processes on the sites cannot be 100% securely correlated to the artefacts on which they were found. In this sense, numerous taphonomic experiments could help to clarify the role that artefacts have in preserving microfossils present in the soil matrix, or the variables that allow microfossils to transfer from plants and the soil to the artefacts. Therefore, even if I discuss the functionality and processing of certain resources on hoes and grinding tools, these could usefully be double-checked with further studies and sampling either from the same or from different sites. Nevertheless, these microfossils can be seen as macro-remains, in the sense

that they are a proxy for the resources that were used on the sites. Further excavations from these and other sites should be done to collect new samples, as well further analyses of the tools, such as morphological, use traces and lipid analysis, amongst others, could help to compare and contrast with the residues analyses undertaken for this study.

The artefacts sampled for microfossil analyses (n= 150) were selected on the basis of their availability in museum collections and other variables related to permits and logistical issues. These circumstances, together with the nature of the archaeological sites in the area, lead to an uneven number of artefacts sampled per period and area. However, most of the sites sampled represent those on which previous interpretations of local prehistory have been constructed, and in this sense, they enrich and challenge previous discussions built on other sorts of evidence. Also, the sites sampled are the sites analysed were ones that had the artefact types that were the focus for previous debate and for this dissertation research (grinding tools and hoes). For future research a wider comprehension of the Formative process and plant management, could be achieved by analysing samples from less represented sites (e.g. Puripica 1) and other kind of artefacts, either for those sites of the period that were not sampled here or from those already sampled, in order to complement current results (e.g. residue analyses from pottery).

Overall, the number of artefacts that had some kind of microfossil was high (95 out of 150), though those which have microfossils classified as cultural were only 43 out of 150 (28%). This low percentage might undermine the significance of the interpretations drawn in this research. As a general rule for residue analyses obtained from artefacts, these cannot be subjected to statistical treatment because identifications start from a reduced number of particles, which then become an even smaller number of taxonomically diagnostic particles (Babot 2004, 207). However, as I mentioned at the beginning of this sub-section, the confidence of the results and interpretations are supported by the fact that they are consistent not just with evidence from local macro-remains but also with a general scenario for the spread of crops and the relevance of certain “wild taxa” such as Cyperaceae, Cactaceae and *Prosopis* and other still “uncertain types” such as tubers. Hence these patterns confirm previous evidence but also give new and previously invisible data, both in tune with current advances in local and worldwide archaeology.

For instance, the argument against maize agriculture arises due to the absence of their diagnostic phytoliths and this was already suggested by Vidal (2007) due to the low number of macro-remains. In this sense, starch grains appear as very redundant. From my own references, the presence of maize itself is difficult to identify from starch, as maize starch can be redundant with other species. This statement was corroborated when I found redundancy with the regular types of *Prosopis*, as Lema *et al.* (2012) has previously stated and Giovannetti *et al.* (2008) have also sketched out. Hence, in arid areas where *Prosopis* is available, reliance on starch grains might not be enough to propose the presence and relevance of maize. In this regard, I need to corroborate previous identifications done in the area during my undergraduate thesis (McRostie 2007). Another important species that was not discussed sufficiently in this study is *Geoffroea decorticans*. Its low presence might be related to distinct processing and preparation techniques being used for this fruit; however, an evaluation of its relevance in the area requires a broader discussion of its management and natural availability among other aspects. Also analyses of camelid dung could be undertaken at Formative sites to evaluate the degree to which *Prosopis* and/or other species provided browsing for these animals. Together with this, it would be desirable to undertake pollen analyses within the oases to get first-hand proxies for and vegetation changes during the Middle and Late Holocene.

By now, some hypotheses enable us to start thinking about these Formative societies as active cultivators, not of domesticated species but of a whole range of wild plants. In fact, I cannot assess the stage of domestication of any of the plants here discussed; some wild species should be re-evaluated in relation to different categories of management and domestication (Clement 1999; Smith 2001b; 2006). Hence, there is a necessity to gather local botanical and genetic information regarding current and archaeological populations of different species in the area, along with other identification of domestication in the landscape. “The archaeological and historical records provide numerous examples of domesticated crop plants that once flourished and have since disappeared, even though their wild relatives continue to thrive in areas where their natural habitat still survives” (Smith 2006, 15).

Further studies of subsequent periods, particularly the Middle period, are needed to track further changes in the human-plant interaction of these middle ground societies and at what point they turn into intense agriculturalists.

CHAPTER X. CONCLUSION

Final remarks

This research was set up to explore the role that plant production had in the subsistence and cultural changes of the Formative period (1400BC-500AD) in the Western Atacama Puna, southern Andes, Chile. This topic has a significance beyond the specific context of the Atacama, as it contributes to a wider need to more fully characterise the social processes and cultural changes taking place during the Formative in the Americas and thus clarify what we mean by 'The Formative' as well as the range of regional variations in the transition from hunters to farmers worldwide.

Previously, plant production in the Atacama during the Formative period has been addressed through a limited number of case studies using plant macro-remains, which were recovered and identified in most cases without proper methodologies. Subsequently the results were interpreted, with an over-emphasis on limited examples, to justify the assumption that the Formative period was characterised by a change to food production (particularly maize agriculture or horticulture). Also on the eve of the Formative period, the appearance of hoes and the morphological change in grinding tools from conical to flat were assumed to represent an increasing dependence on crops. Previous researchers have explained the occupation of the oases, an increase in sedentism, the rise of villages and developments in social hierarchy through an emphasis on agriculture and a lesser emphasis on gathering or horticulture.

Although these theoretical assumptions and hypothesis have been re-evaluated for other parts of the Americas, they have continued to dominate interpretations of the Formative period in the Atacama. A major reason for this uncritical imposition of external models has been the lack of consistent evidence for plant use at Formative period sites to better evaluate these ideas. Thus this research aimed to develop a new approach to gathering data related to plant production, processing and consumption in order to fill these empirical gaps

and critically evaluate what was actually happening during the Formative changes, by evaluating the contribution of wild plants and crops within changing subsistence strategies.

I developed and applied new methodologies to identify plant microfossils sampled from artefacts (lithic hoes and grinding tools) from Late Archaic and Formative sites as well as collecting and cataloguing a reference collection of local plants in order to aid the identification of these microfossils. I also attempted to use isotope analyses on human bones to evaluate what these individuals were consuming. The resulting data were used to evaluate some of the models and premises used in the area by addressing the following research questions:

1. What plants were dominant and how were they managed by the Formative peoples living in the Atacama Region? Why and how do these patterns vary through time and space?
2. Why do lithic hoes appear during the Early Formative? Are they related to farming practices?
3. Why were new grinding technologies adopted? Are they related to the processing of new resources (crops)?
4. Why were previous occupations in the ravines abandoned and new permanent settlements in the oases established during the Formative period? Is this related to the onset of plant production?
5. Is it possible to identify whether these changes are autochthonous or whether they relate to new populations moving into the area?

The main empirical findings were shown and discussed in detail in Chapters VIII and IX. The microfossil analysis found that the Formative societies continued to rely on many of the same wild plants (Cyperaceae, Cactaceae, tubers) as the Late Archaic populations used, though Formative societies also incorporated other plants that might have been known previously but became exploited to a far greater extent (e.g. *Prosopis* and other tuber types).

For the Early and Late Formative, the patterns of plants identified are consistent with recent research in terms of the continuing relevance of wild plants, and this was used to raise issues about the potential management and impact of human-plant interaction for diverse wild taxa. Different activities and categories of plant management were discussed for each taxon, redefining the idea of gathering as wild plant production and giving a new basis from

which to explore the middle ground. For the Late Formative, this research allocates a minor role to crops in comparison to previous interpretations, leading to a re-evaluation of the evidence for agriculture or horticulture in the region. Also, and for the first time in the Atacama, a recurrent and important presence of tubers has been recorded, although it has not been possible to determine their taxonomy or their status as domestic or wild plants using the microfossil starches. But this presence is consistent with current proposals about the early management of tubers by Late Archaic and Formative societies in the Andes. Indeed, the exploitation of underground organs of Cyperaceae species have been recorded worldwide as components of pre-modern subsistence economies, just as Cactaceae or *Prosopis* have been described archaeologically and ethnographically as major staples in the economies of populations living in a range of arid and semiarid lands.

In this regard, the fact that our evidence for *Prosopis* dates exclusively to the Late Formative leads me to propose that the “wild” status of this tree should be re-evaluated, as there is a possibility that its entrance and posterior expansion and naturalisation within the oases of the Atacama could have been caused by deliberate selection and planting by humans or through some other symbiotic relationship that benefited the plants, herds and humans. Hence, within farming, silviculture or arboriculture should be considered.

The microfossils of some crops (Cucurbitaceae and *Capsicum* sp.) were identified based on previous publications and therefore their identification should be further tested with more detailed comparative samples; also, their minimal presence and the lack of a clear pattern in the archaeological record play against a secure identification. However, their possible presence at an early date is consistent with their early appearance in other parts of the Andes and with previous reporting in small quantities as macro-remains in the Atacama. However, this scant evidence does not support arguments for an economy dependence on agriculture or horticulture in the oases during the Late Formative: the scarce presence of starches on a wide sample of tools does not sustain arguments for the intense production of these products nor their role as a main staple within the subsistence of these Formative populations. The lack of maize phytoliths, the redundant starch grain of maize/*Prosopis*, and the low presence of maize macro-remains argues against previous hypotheses of a dependence on maize horticulture and agriculture in the oases. If some horticulture of

maize was performed, it is probably better understood as a very limited production for maize consumption at specific social and/or ritual activities.

Stable isotopes, although not conclusive, show the consumption of both C3 and C4 plants, though C3 values are higher in apatite, which can reflect either fruits of *Prosopis*, *Geoffroea decorticans*, Cyperaceae and/or tubers, whilst C4 could reflect the consumption of Cactaceae or some maize. Cyperaceae and Cactaceae have already been reported in guts and coprolites of Formative populations. The collagen also presents C4 values that might come from camelids eating C4 plants such as *Atriplex* or C4 grasses. It is not clear how nitrogen levels reflect diet patterns; it is possible that the aridity of the area has influenced nitrogen levels, making the readings difficult to interpret.

Analyses of microfossil residues on artefacts permit a more critical review of resources processed by these tools and thus their function. Grinding tools cannot be related to any specific resource, as frequently multiple resources are processed on them during their lifetime. In the Atacama, the change from conical to flat mortars does not seem to be related to any change in the resources processed within them, as there is a clear continuity in the range of plants ground from the Late Archaic through to the Formative period, such as Cyperaceae or tubers, together with the incorporation of *Prosopis* during the Formative period. Whatever the main causes of the change in grinding stone morphology, these were strong enough to replace the old model almost completely by the end of the Formative period. I cannot rule out ideological, taste, foodways and/or more pragmatic reasons, though it is likely that flat surfaces allow improving bio-accessibility and productivity due to the reduced effort involved in the grinding task. Hoes also seem to be multifunctional tools, where management of wild and/or domesticated plants could have been just one of their functions. Activities related with a more sedentary life, like cleaning debris from structures, building structures or digging tombs, as well as managing animal corrals or water flows to encourage natural vegetation patches for grazing or for small gardens with wild and domestic plants, could all have been performed more efficiently with this tool. The multiple types of microfossils and taxa identified on hoes support this multi-functional proposition. Thus, although the two tools which have been most consistently used to interpret agriculture and crop processing could occasionally have been used for planting and

processing traditional crops, the residue analyses show that they were only rarely used for these activities. There are many variables affecting these societies within which plant selection is unlikely to have been the only one that caused a shift from conical to flat mortars. To an even greater extent, hoes were multifunctional tools related to changing use of space and resources. These adaptable tools could have had an initial role within the contexts of risk-spreading strategies such as managing animal corrals and more intensive use of *Prosopis* and irrigation, and become essential in agricultural production only at a later date, when higher levels of production and/or productivity were adopted.

Regarding the occupation of the oases, several indicators convince me that the main reason why this occupation occurs during this phase is the control over camelid herds and the potential to exploit them within this environment, rather than the previously proposed shift from herding to horticulture/agriculture. Previously, herding of camelids on the oases was excluded from discussion based on the erroneous assumption about the restricted ecological reach of camelids; however, multiple examples show that llamas can be cared for and bred in many environments. Herding in the oases is in agreement with the corrals in Tular 1 and the occupation by herders of Tular 85, and can now be confirmed by presence of spherulites that I have identified on hoes from oases sites. The lack of any strong evidence of crops during the initial move to the oases sites also argues against agricultural production as the main reason for colonising the oases. Hence my alternative suggestion is that *Prosopis* forests started to be cultivated and/or managed by Formative society's before traditional agriculture of annual crops. This is consistent with the potential role that camelids could have had in the initial oases settlements, through the development of a silvo-pastoralist system in the oases rather than the previous proposal of a separation between herding activities by groups in the ravines versus agriculture orientated groups in the oases. Herding life requires some degree of mobility, which could explain the scarce presence of residential sites in the oases during the Formative period as well as the sand layers within the first occupation of Tular 1 and its cellular growth, which, more than a hierarchisation of the system, could reflect seasonal or episodic occupations. Hence the occupation of riverbed locations might not only have been related to plant management

strategies for human consumption (e.g. *Scirpus*) but also to the herders' need to support their grazing animals.

However, this prevailing aspect of herder mobility throughout the Formative period must be considered in relation to the development of more permanent long-term and complex settlements that characterise complex hunter-gatherers and increase through later periods when ties to landscape and resources strengthen. In this regard, archaeobotanical data suggest a reduced mobility in the preference for exploiting nearby resources (e.g., *Prosopis* on the oases and Cyperaceae on the ravines), though there is also a cross-presence of these resources between sites (e.g., some *Prosopis* at ravine sites), and this is in tune with multiple archaeological and ethnographic evidence for the simultaneous use of distinct environmental zones and spread of individuals in the Atacama. However, further analyses and other kinds of evidence should be analysed to define the nature of sedentarism and the degree of social division within these groups. In this regard, silviculture could be initially started or promoted either by the permanence of some part of the group settling within the oases or occasional management during short visits when different techniques to protect these trees may have been applied.

Finally the microfossils and isotopes suggest continuity in the use of resources through time and space, signifying that there was no replacement of the local population. I do not deny the dynamism of Formative societies and that some of the initial changes might have been influenced by outside ideas or individuals. However, the archaeological patterns indicate a continuity of tradition between the oases and the ravines and from the Late Archaic to the Late Formative, and thus undermine the suggestion of a radical new influx of agriculturalists coming to the oases in the Late Formative. This last argument was also supported to a very limited extent by the scarce $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{18}\text{O}$ isotopes in bone sampled, which did not indicate any population replacement.

Thus, what matters in the discussion and interpretation of plant remains and isotope values of Formative Atacama societies is the management and engagement that these populations had with the plants and how this relation evolved to higher levels of dependence between the two. Hence, rather than discriminating between agriculture, horticulture and gathering, we need to develop more flexible categories to look at societies that are low food producers

within the middle ground between procurers and more intense agriculturalists. In this middle ground, we can discuss several levels of dependence and subsistence and re-evaluate the different levels and stages of domestication for different taxa and landscapes, including developments in the management of plant growth for the benefit of animal herds.

Risk-spreading strategies are useful to explain many of the changes that were on-going during the Formative period. The adoption of new technologies and plants, or the movement to further ecological areas, could all have been done as risk-spreading strategies that help to reinforce cultural and social viability. This strategy is more likely to have been at the core of decision-making of Formative societies, rather than the models of food-stresses that have been used to explain the hypothesised adoption of agriculture.

Hence the patterns of plant use reinforce and clarify the role and nature of wild and domestic plant production within a broader subsistence economy. The previous agro-pastoralist definition for Formative societies (with its divisions between animal herding based in the upper belts as opposed to plant production based in the oases) loses validity when we re-conceive this as an integrated society of silvo-pastoralists and eventually as silvo-agro-pastoralists. This study provides new answers to old questions and re-evaluates local models for the Formative period, adding new elements into the broader discussion of the Formative development and the long slow change from hunter-gatherers to farmers. However, it also has several limitations and presents challenges for future research.

Future Research

The main limitation of this study arises from the sampling. In spite of early work to achieve an ambitious sample base, the final count of artefacts from good contexts and with microfossils that could contribute to cultural interpretation was relatively low. This could not have been predicted beforehand, and it has still provided an important complement to previous archaeological data, identifying plants that had not previously been recorded at Formative sites in the Atacama. But, for this new avenue of research to be developed in the future, there is a need to take new samples from these and other sites as well sample a larger number of artefacts with a more secure archaeological context. The current research has provided a first systematic study for the northern Chilean area, developing new

reference collections, presenting a baseline for future comparison and highlighting methodological issues that can be developed in the future. Isotope evidence was also limited by the number of samples analysed, and, again, there is a need to build up a larger comparative database for the region. But there is a strong potential for isotope studies to contribute to the debates presented in this dissertation regarding, for instance, the role of maize in Formative economies, although there needs to be a more detailed consideration of the different fractionation models and the complications that affect nitrogen values in arid environments and regarding how the diet of camelids affects the composition of humans who consume their meat.

There is a lot to be gained by continuing microfossil research and this requires a further development and expansion of the reference collections by integrating new species and identifying those species which could not be identified to species level. For this to be advanced, interdisciplinary work with botanists and ecologists should be developed in order to address the diversity of species and varieties of different genera or families in the area (e.g. *Prosopis*, *Solanum*) and to help identify the different level of management that wild plants were potentially subjected to and whether this category should be re-evaluated within different domestication levels. Also, paleo-environmental studies with pollen and other microfossil cores from within the oases could permit a better understanding of cultural and environmental relations within this ecosystem during the past, including the emergence of *Prosopis* and *Geoffroea* forests. Camelids' dung composition should also be examined as a proxy for the presence of these forests and their relations with camelids.

Systematic studies should be carried out on grinding tools and hoes from the Archaic to the Formative periods regarding their typologies, use wear and contexts, including the potential to undertake lipid analyses. Regarding the microfossils and taxa identified in this study, these could be contrasted and compared by sampling other contexts such as pottery and soils.

Overall, the main objectives of this research were answered by collecting and analysing new types of evidence. The results of these analyses lead to the proposal of a new model and an alternative explanation for the Formative societies of Atacama. While this has contributed a further example to the rich and diverse spectrum that lies between hunter-gatherers and

farmers worldwide, there is much more research that needs to be done before we will fully understand how Andean people made use of the Atacama's rich but demanding environment.

References

- Adams, J.L., 1993. Toward understanding the technological development of manos and metates. *Kiva* 58(3), 331-344.
- Adams, J.L., 1999. Refocusing the role of food-grinding tools as correlates for subsistence strategies in the U.S. Southwest. *American Antiquity* 64(3), 475-498.
- Adán, L. and Urbina, S., 2007. Arquitectura Formativa en San Pedro de Atacama. *Estudios Atacameños* 34, 7-30.
- Agüero, C., 2005. Aproximación al asentamiento humano temprano en los oasis de San Pedro de Atacama. *Estudios Atacameños* 30, 29-60.
- Agüero, C. and Uribe, M., 2011. Las sociedades Formativas de San Pedro de Atacama: Asentamiento, cronología y proceso. *Estudios Atacameños* 42, 53-78.
- Agüero, C., Uribe, M. and Carrasco, C., 2009. Current research in San Pedro de Atacama. *Andean Past* 9, 323-328.
- Albert, R.M., 1999. Study of ash layers through phytolith analyses from the Middle Paleolithic levels of Kebara and Tabun caves. Universitat de Barcelona.
- Aldenderfer, M., 1998. *Montane foragers: Asana and the South-Central Andean Archaic*. Iowa: University of Iowa Press.
- Aldenderfer, M., 2006. Costly signaling, the sexual division of labor, and animal domestication in the Andean Highlands. In: D. Kennet & B. Winterhalder (eds.), *Behavioral ecology and the transition to agriculture*. London: University California Press, 167-196.
- Aldunate, C., Armesto, J., Castro, V. and Villagrán, C., 1983. Ethnobotany of pre-Altiplanic community in the Andes of Northern Chile. *Economic Botany* 37(1), 120-135.

- Aldunate, C., Berenguer, J., Castro, V., Cornejo, L., Martínez, J.L. and Sinclair, C., 1986. Sobre la cronología del Loa superior. *Chungara* 16/17, 333-346.
- Ambrose, S.H., 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science* 17(4), 431-451.
- Ambrose, S.H., 1993. Isotopic analysis of paleodiets: methodological and interpretive considerations. In: M.K. Sandford (ed.), *Investigations of ancient human tissue, chemical analysis in anthropology*. Pennsylvania: Gordon and Breach, 59-130.
- Ambrose, S.H., Butler, B., Hanson, D., Hunter-Anderson, R. and Krueger, H., 1997. Stable isotopic analysis of human diet in the Marianas Archipelago, Western Pacific. *American Journal of Physical Anthropology* 104(3), 343-361.
- Ambrose, S.H. and De Niro, M., 1986. Reconstruction of African human diet using bone collagen carbon and nitrogen isotope ratios. *Nature* 319(6051), 321-324.
- Ambrose, S.H. and Norr, L., 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: J. Lambert & G. Grupe (eds.), *Molecular archaeology of prehistoric human bone*. Berlin: Springer, 1-37.
- Ames, M., Salas, A. and Spooner, M., 2008. A morphometric study of species boundaries of the wild potato *Solanum* series Piurana (Solanaceae) and putatively related species from seven other series in *Solanum* sect. Petota. *Systematic Botany* 33566-578.
- Ammerman, A.J. and Cavalli-Sforza, L.L., 1973. The explanation of culture change. In: C. Renfrew (ed.), *Models in prehistory*. London: Duckworth, 343-358.
- Ammerman, A.J. and Cavalli-Sforza, L.L., 1984. *The Neolithic transition and the genetics of populations in Europe*. Princeton: Princeton University Press.
- Arana, M.M., 1999. El tiempo de la algarroba. In: C. Aschero, M.A. Korstanje & P. Vuoto (eds.), *En los tres reinos: prácticas de recolección en el Cono Sur de América*.

- Tucumán: Instituto de Arqueología y Museo, Facultad de Ciencias Naturales e Instituto Miguel Lillo, Universidad Nacional de Tucumán, 197-203.
- Aranda, X., 1961-64. San Pedro de Atacama, elementos diagnósticos para un plan de desarrollo local. *Informaciones Geográficas* XI-XIV 9-61.
- Aranibar, J., Lopez, S., Colaneri, M., Romano, A., Macko, S. and Aschero, C., 2007. Dieta y sociedades agropastoriles: análisis de isótopos estables de un sitio de la Puna Meridional Argentina (Antofagasta de la Sierra, Catamarca). *Comechingonia* 10, 29-48.
- Arias, G., Benavente, A. and Gecele, P., 1991. Identificación y variabilidad del uso del animal a través de textiles arqueológicos: contraste con patrones fanéreos actuales. *Actas del XII Congreso Nacional de Arqueología Chilena*. 151-162.
- Atalay, S. and Hastorf, C., 2006. Food, meals, and daily activities: food habitus at Neolithic Catalhöyük. *American Antiquity* 71(2), 283-319.
- Atchison, J. and Fullagar, R., 1998. Starch residues on pounding implements from Jinmium rockshelter. In: R. Fullagar (ed.), *A closer look: recent Australian studies of stone tools*. Sydney: University of Sydney, 109-125.
- Aufderheide, A.C., Kelley, M.A., Rivera, M., Gray, L., Tieszen, L.L., Iversen, E., Krouse, H.R. and Carevic, A., 1994. Contributions of chemical dietary reconstruction to the assessment of adaptation by ancient highland immigrants (Alto Ramirez) to coastal conditions at Pisagua, North Chile. *Journal of Archaeological Science* 21(4), 515-524.
- Babot, M.P., 2003. Starch grain damage as an indicator of food processing. In: D.M. Hart & L.A. Wallis (eds.), *Phytolith and starch research in the Australian-Pacific-Asian Regions: the state of the art*. Canberra: Pandanus Books, 69-81.
- Babot, M.P., 2004. Tecnología y utilización de artefactos en el Noroeste prehispánico. Unpublished PhD Thesis, Universidad Nacional de Tucumán.

- Babot, M.P., 2006. El papel de la molienda en la transición hacia la producción agropastoril: Un análisis desde la Puna Meridional Argentina. *Estudios Atacameños* 32, 75-92.
- Babot, M.P., 2007. Granos de almidón en contextos arqueológicos: posibilidades y perspectivas a partir de casos del Noroeste Argentino. In: B. Marconetto, M.P. Babot & N. Oliszewski (eds.), *Paleoetnobotánica del Cono Sur. Estudios de caso y propuestas metodológicas*. Córdoba: Centro Editorial de la Facultad de Filosofía y Humanidades, Universidad Nacional de Córdoba.
- Babot, M.P. and Bru De Labanda, E., 2005. Analysis of three factors that have an influence on the preservation of microfossils in archaeological artefacts. *Phytolitharien: Bulletin of the Society for Phytolith Research* 17(2), 4-5.
- Bandy, M., 2001. Population and history in the ancient Titicaca Basin. Unpublished PhD thesis, University of California, Berkeley.
- Bar-Yosef, O. and Belfer-Cohen, A., 1989. The origins of sedentism and farming communities in the Levant. *Journal of World Prehistory* 40(3), 447-498.
- Bar-Yosef, O. and Meadow, R., 1995. The origins of agriculture in the Near East. In: T.D. Price & A.B. Gebauer (eds.), *Last hunters, first farmers: new perspectives on the prehistoric transition to agriculture*. Santa Fe: School of American Research Press, 39-94.
- Barberena, R., 2002. *Los límites del mar. Isótopos estables en Patagonia Meridional*. Buenos Aires: Sociedad Argentina de Antropología.
- Barón, A.M., 1986. Tular: posibilidades y limitaciones de un ecosistema. *Chungara* 16/17, 149-158.
- Barros, S. and Wrann, J., 1992. El género *Prosopis* en Chile. *Ciencia e Investigación Forestal* 6(2), 296-334.
- Barrows, D.P., 1900. *The ethno-botany of the Coahuilla Indians of Southern California*. Chicago: University of Chicago Press.

- Barton, H., 2007. Starch residues on museum artefacts: implications for determining tool use. *Journal of Archaeological Science* 34(10), 1752-1762.
- Barton, H., 2009. Starch granule taphonomy: the results of a two year field experiment. In: M. Haslam, G. Robertson, A. Crowther, S. Nugent & L. Kirkwood (eds.), *Archaeological science under a microscope: studies in residue and ancient DNA analysis in honour of Thomas H. Loy*. Canberra: ANU E Press, 129-140.
- Barton, H. and Matthews, P.J., 2006. Taphonomy. In: R. Torrence & H. Barton (eds.), *Ancient starch research*. Walnut Creek: Left Coast Press, 75-94.
- Basehart, H., 1974. *Mescalero Apache subsistence patterns and socio-political organization*. New York: Garland Publishing.
- Bellwood, P.S. and Renfrew, C., 2002. *Examining the farming/language dispersal hypothesis*. Cambridge: McDonald Institute for Archaeological Research.
- Belmar, C. and Quiroz, L., 2005. *Informe análisis carpológico. Cementerio Regimiento Chorrillos*. Unpublished report.
- Benavente, A., 1978. Chiu Chiu 200. Poblado agro-alfarero temprano. *Revista Chilena de Antropología* 1, 5-12.
- Benavente, A., 1981. Chiu-Chiu 200: un campamento de pastores. Unpublished undergraduate thesis, Universidad de Chile.
- Benavente, A., 1982. Chiuchiu 200: Una comunidad pastora temprana en la Provincia del Loa (II Región). In Scha (ed.) *Actas del IX Congreso Nacional de Arqueología Chilena*. La Serena, 75-94.
- Benavente, A., 1988-1989. Nuevas evidencias arqueológicas acerca de los asentamientos tempranos en el Loa Medio. *Paleoetnológica* 5, 65-71.
- Bender, B., 1978. Gatherer-hunter to farmer: a social perspective. *World Archaeology* 10(2), 204-222

- Benoit, I., 1989. *Libro rojo de la flora terrestre de Chile*. Santiago: Corporación Nacional Forestal de Chile.
- Bentley, R.A., 2006. Strontium isotopes from the earth to the archaeological skeleton: a review. *Journal of Archaeological Method and Theory* 13(3), 135-187.
- Benz, B.F., 2001. Archaeological evidence of teosinte domestication from Guilá Naquitz, Oaxaca. *Proceedings of the National Academy of Sciences* 98(4), 2104-2106.
- Benz, B.F. and Staller, J., 2006. The Antiquity, Biogeography, and Culture History of Maize in the Americas. In: J. Staller, R. Tykot & J. Benz (eds.), *Histories of Maize Multidisciplinary Approaches to the Prehistory, Linguistics, Biogeography, Domestication, and Evolution of Maize*. San Diego: Elsevier, 665-672.
- Berenguer, J. and Dauelsberg, P., 1989. El Norte Grande en la órbita de Tiwanaku. In: J. Hidalgo, V. Schiappacasse, H. Niemeyer, C. Aldunate & I. Solimano (eds.), *Culturas de Chile: prehistoria. Desde sus orígenes hasta los albores de la conquista*. Santiago: Andrés Bello, 129-180.
- Berenguer, J., Roman, A., Deza, A. and Llagostera, A., 1988. Testing a cultural sequence for the Atacama Desert. *Current Anthropology* 29(2), 341-346.
- Berenguer, J., Roman, Á., Deza, Á. and Llagostera, A., 1986. La secuencia de Myriam Tarragó para San Pedro de Atacama: un test por termoluminiscencia. *Revista Chilena de Antropología* 5, 17-54.
- Beresford-Jones, D., 2011. *The lost woodlands of ancient Nasca : a case-study in ecological and cultural collapse*. Oxford ; New York: Published for the British Academy by Oxford University Press.
- Beresford-Jones, D.G., 2004. Pre-Hispanic Prosopis-human relationships on the south coast of Peru: riparian forests in the context of environmental and cultural trajectories of the Lower Ica Valley. Unpublished PhD thesis, University of Cambridge.

- Beresford-Jones, D.G., Alarcón, C., Arce, S., Chepstow-Lusty, A., Whaley, O., Sturt, F., Gorriti, M., Portocarrero, O. and Cadwallader, L., 2011a. Ocupación y subsistencia del Horizonte Temprano en el contexto de cambios ecológicos de largo plazo en las Cuencas de Samaca y Ullujaya, valle bajo de Ica. *Boletín de Arqueología PUCP* 13, 237-257.
- Beresford-Jones, D.G., Arce, S., Whaley, O. and Chepstow-Lusty, A., 2009a. The Role of Prosopis in Ecological and Landscape Change in the Samaca Basin, Lower Ica Valley, south coast Peru from the Early Horizon to the Late Intermediate Period. *Latin American Antiquity* 20303-332.
- Beresford-Jones, D.G., Lewis, H. and Boreham, S., 2009b. Linking cultural and environmental change in Peruvian prehistory: Geomorphological Survey of the Samaca Basin, Lower Ica Valley. *Catena* 78234-249.
- Beresford-Jones, D.G., Whaley, O., Alarcón, C. and Cadwallader, L., 2011b. Two millennia of changes in human ecology: archaeobotanical and invertebrate records from the lower Ica valley, south coast Peru. *Vegetation History and Archaeobotany* 20(4), 273-292.
- Berman, M.J. and Pearsall, D., 2008. At the crossroads: starch grain and phytolith analyses in Lucayan prehistory. *Latin American Antiquity* 19(2), 181-203.
- Bertrand, A., 1885. *Memoria sobre las cordilleras del Desierto de Atacama i rejiones limítrofes*. Santiago: Imprenta Nacional.
- Betancourt, J., Latorre, C., Rech, J., Quade, J. and Rylander, K., 2000. A 22000-Year record of monsoonal precipitation from Northern Chile's Atacama Desert. *Science* 289(5484), 1542-1546.
- Bibar, G., 1966 [1558]. *Crónica y relación copiosa y verdadera de los Reynos de Chile*. Santiago: Fondo Historico y Bibliografico Jose Toribio Medina.
- Binford, L.R., 1968. Post-pleistocene adaptations. In: S. Binford & L. Binford (eds.), *New perspectives in archaeology*. Chicago: Aldine, 313-342.

- Bird, R.M., 1966. El maíz y las divisiones étnicas en la sierra de Huanuco. *Cuadernos de Investigación* 1, 34-44.
- Bird, R.M., 1970. Maize and its cultural and natural environments in the sierra of Huanuco, Peru. Unpublished PhD thesis, University of California.
- Bittmann, B., Le Paige, G. and Núñez, L., 1978. *Cultura Atacameña*. Santiago: Ministerio de Educación.
- Blake, M., 2006. Dating the initial spread of *Zea mays*. In: J. Staller, R. Tykot & B.F. Benz (eds.), *Histories of maize: multidisciplinary approaches to the prehistory, biogeography, domestication, and evolution of maize*. Amsterdam: Elsevier, 55-72.
- Bobst, A.L., Lowenstein, T.K., Jordan, T.E., Godfrey, L.V., Ku, T.L. and Luo, S., 2001. A 106ka paleoclimate record from drill core of the Salar de Atacama, Northern Chile. *Palaeogeography, Palaeoclimatology, Palaeoecology* 173(1–2), 21-42.
- Bohrer, V.L., 1981. Methods of recognizing cultural activity from pollen in archaeological sites. *Kiva* 46(3), 135-142.
- Bohrer, V.L. and Adams, K., 1977. *Ethnobotanical techniques and approaches at Salmon Ruin, New Mexico*. Portales: Eastern New Mexico University.
- Boman, E., 1908. *Antiquités de la région andine de la République Argentine et du désert d'Atacama*. Paris: Imprimerie nationale.
- Bourdieu, P., 1984. *Distinction: a social critique of the judgement of taste*. London: Routledge.
- Bowdery, D., 2001. Phytolith and starch data from an obsidian tool excavated at Bitokara, New Britain Province, Papua New Guinea. In: J.D. Meunier & F. Colin (eds.), *Phytoliths: applications in earth sciences and human history*. Lisse; Abingdon: A.A. Balkema, 225-237.

- Boyd, W.E., C.J. Lentfer, and R. Torrence, 1998. Phytolith analysis for a wet tropics environment: methodological issues and implications for the archaeology of Garua Island, West New Britain, Papua New Guinea. *Palynology* 22, 213-228.
- Bozarth, S.R., 1992. Classification of opal phytoliths. In: G. Rapp & S.C. Mulholland (eds.), *Phytolith systematics: emerging issues*. New York: Plenum Press, 193-214.
- Bozarth, S.R., 1996. Pollen and opal phytolith evidence of prehistoric agriculture and wild plant utilization in the Lower Verde River Valley, Arizona. Unpublished PhD thesis, University of Kansas.
- Bray, W., Herrera, L., Schrimpff, M.C., Botero, P. and Monsalve, J.G., 1987. The ancient agricultural landscape of Calima, Colombia. In: W. Denevan, K. Mathewson & G. Knap (eds.), *Pre-Hispanic agricultural fields in the Andean region*. Oxford: BAR, 443-481.
- Browman, D., 1987a. Agro-pastoral risk management in the Central Andes. *Research in Economic Anthropology* 8:171-200.
- Browman, D., 1987b. Introduction: risk management in Andean arid lands. In: D. Browman (ed.), *Arid land use strategies and risk management in the Andes. A regional anthropological perspective*. Boulder, CO: Westview, 1-23.
- Browman, D., 1987c. Pastoralism in Highland Peru and Bolivia. In: D. Browman (ed.), *Arid land use strategies and risk management in the Andes. A regional anthropological perspective*. Boulder, CO: Westview, 121-150.
- Brown, P., 1987. Economy, ecology and population: recent changes in Peruvian Aymara land use patterns. In: D. Browman (ed.), *Arid land use strategies and risk management in the Andes*. Boulder, CO: Westview Press, 99-120.
- Bruhns, K.O., 1994. *Ancient South America*. Cambridge; New York: Cambridge University Press.

- Bruno, M.C., 2001. Formative agriculture? The status of *Chenopodium* domestication and intensification at Chiripa, Bolivia (1500 B.C.-100 B.C.). Unpublished thesis (A.M.), Washington University.
- Bruno, M.C., 2006. A morphological approach to documenting *Chenopodium* domestication in the Andes. In: M. Zeder, D. Bradley, E. Emshwiller & B.D. Smith (eds.), *Documenting domestication: new genetic and archaeological paradigms*. Berkeley: University of California Press, 32-45.
- Bruno, M.C., 2008. Waranq Waranqa: ethnobotanical perspectives on agricultural intensification in the Lake Titicaca Basin (Taraco Peninsula, Bolivia). Unpublished PhD thesis, Washington University.
- Bruno, M.C. and Whitehead, W.T., 2003. *Chenopodium* cultivation and Formative period agriculture at Chiripa, Bolivia. *Latin American Antiquity* 14(3), 339-355.
- Brush, S.B., 1976. Man's Use of an Andean Ecosystem. *Human Ecology* 4(2), 147-166.
- Brush, S.B., 1982. The natural and human environment of the Central Andes. *Mountain Research and Development* 2(1), 19-38.
- Bryant, V.M., Jr. and Holloway, R.G., 1983. The role of palynology in archaeology. *Advances in Archaeological Method and Theory* 6, 191-224.
- Bueno, L., 2003. *Flotación en Tu-85*. Proyecto Fondecyt 1020316. Unpublished report.
- Bukasov, S., 1973. Cytogenetic basis of the evolution of potato species of the genus *Solanum* L. Section *Tuberosum* (Dun.) Buk. . *Soviet Genetics* 6463-471.
- Burger, R. and Van Der Merwe, N., 1990. Maize and the origin of Highland Chavín Civilization: an isotopic perspective. *American Anthropologist* 92(1), 85-95.
- Burkart, A., 1976. *A monograph of the genus Prosopis: (Leguminosae subfam. mimosoideae)*. Cambridge: Arnold Arboretum.

- Bush, M., Piperno, D. and Colinvaux, P., 1989. A 6000 year history of Amazonian maize cultivation *Nature* 340(6231), 303-305.
- Bustamante, M.M.C., Martinelli, L.A., Silva, D.A., Camargo, P.B., Klink, C.A., Domingues, T.F. and Santos, R.V., 2004. ^{15}N natural abundance in woody plants and soils of Central Brazilian Savannas (Cerrado). *Ecological Applications* 14(4), 200-213.
- Cabanes, D., Gadot, Y., Cabanes, M., Finkelstein, I., Weiner, S. and Shahack-Gross, R., 2012. Human impact around settlement sites: a phytolith and mineralogical study for assessing site boundaries, phytolith preservation, and implications for spatial reconstructions using plant remains. *Journal of Archaeological Science* 39(8), 2697-2705.
- Cadwallader, L., Beresford-Jones, D.G., Whaley, O. and O'connell, T., 2012. The signs of maize? A reconsideration of what $\delta^{13}\text{C}$ values say about palaeodiet in the Andean Region. *Human Ecology* 40(4), 487-509.
- Calo, C. and Cortes, L., 2009. A contribution to the study of diet of formative societies in northwestern Argentina: isotopic and archaeological evidence. *International Journal of Osteoarchaeology* 19(2), 192-203.
- Campos, S., Del Puerto, L. and Inda, H., 2001. Opal phytolith analysis: its applications to the archaeobotanical record in the East of Uruguay. In: J.D. Meunier & F. Colin (eds.), *Phytoliths: applications in earth sciences and human history*. Lisse; Abingdon: A. A. Balkema, 129-142.
- Cane, S., 1989. Australian Aboriginal seed grinding and its archaeological record: a case study from the Western Desert. In: D.R. Harris & G.C. Hillman (eds.), *Foraging and farming: the evolution of plant exploitation*. London: Unwin Hyman, 99-119.
- Capparelli, A., 2008. Caracterización cuantitativa de productos intermedios y residuos derivados de alimentos del algarrobo (*Prosopis flexuosa* y *P. chilensis*, Fabaceae): aproximación experimental aplicada a restos arqueobotánicos desecados. *Darwiniana* 46(2), 175-201.

- Capriles, J.M., Calla, S. and Albarracín-Jordán, J., 2011. Tecnología lítica y estrategias de subsistencia durante los períodos Arcaico y Formativo en el Altiplano Central, Bolivia. *Chungara* 43(1), 455-468.
- Cárdenas, M., 1969. *Manual de plantas económicas de Bolivia*. Cochabamba: Editorial Los Amigos del Libro.
- Cárdenas, U., 1998. Entre el tolar y el pajonal: Percepción ambiental y uso de plantas en la comunidad atacameña de Talabre, II Región, Chile. *Estudios Atacameños* 16, 251-282.
- Carevic, F., Carevic, A. and Delatorre, J., 2012. Historia natural del género *Prosopis* en la Región de Tarapacá. *Idesia* 30, 113-117.
- Carrasco, C., 2003. Los artefactos de molienda durante los períodos Intermedio Tardío y Tardío en San Pedro de Atacama y Loa Superior. *Estudios Atacameños* 25, 35-53.
- Carrasco, C., 2006. *Materialidad lítica de sitios habitacionales Formativos de la quebrada de Vilama y oasis de San Pedro de Atacama*. Proyecto FONDECYT 1030931. Unpublished report.
- Cartajena, I., 1994. Determinación de restos óseos de camélidos en dos yacimientos del Loa Medio (II Región). *Estudios Atacameños* 11, 25-52.
- Cartajena, I., 1995. Determinación de restos óseos de camélidos en dos registros mixtos, Chiu-Chiu Cementerio. *Hombre y Desierto* 9291-308.
- Cartajena, I. and Carrasco, C., 2009. *Anexo N°3 Monografía: Prospección De Conjunto y Estructuras En Tulán-85*. Santiago.
- Cartajena, I., Núñez, L. and Grosjean, M., 2003. Los camélidos en la vertiente occidental de la Puna de Atacama: una visión desde el Arcaico Temprano al Formativo Temprano. *III Taller Internacional de Zooarqueología de Camélidos Sudamericanos*. Tilcara.

- Cartajena, I., Núñez, L. and Grosjean, M., 2007. Camelid domestication on the western slope of the Puna de Atacama, northern Chile. *Anthropozoologica* 42(2), 155-173.
- Cartmell, L.W., Aufderheide, A.C., Springfield, A., Weems, C. and Arriaza, B., 1991. The frequency and antiquity of prehistoric coca-leaf-chewing practices in Northern Chile: radioimmunoassay of a cocaine metabolite in human-mummy hair. *Latin American Antiquity* 2(3), 260-268.
- Casas, A. and Caballero, J., 1996. Traditional management and morphological variation in *Leucaena esculenta* (Fabaceae: Mimosoideae) in the Mixtec Region of Guerrero, Mexico. *Economic Botany* 50(2), 167-181.
- Casas, A., Pickersgill, B., Caballero, J. and Valiente-Banuet, A., 1997. Ethnobotany and domestication in Xoconochtli, *Stenocereus stellatus* (Cactaceae), in the Tehuacán Valley and La Mixteca Baja, México. *Economic Botany* 51(3), 279-292.
- Castro, M. and Bahamondes, M., 2001. Summer rains in the arid zones of the Andes mountain: the case of the Aymaras and the Atacameños. *Open Meeting of the Human Dimensions of Global Environmental Change Research Community*. Río de Janeiro, Brazil.
- Castro, V., 2008. La papa (*Solanum* sp.) contexto social e ideológico en sus zonas de desarrollo originarias. *Revista del Jardín Botánico Chagual* VI(6), 33-43.
- Castro, V., Aldunate, C. and Berenguer, J., 1984. Orígenes altiplánicos de la Fase Toconce. *Estudios Atacameños* 7, 159-178.
- Castro, V., Aldunate, C. and Varela, V., 2004. Ocupación humana del paisaje desértico de Atacama, Región de Antofagasta. *ARQ* 57, 14-17.
- Castro, V. and Tarragó, M., 1992. Los inicios de la producción de alimentos en el Cono Sur de Sud América. *Revista de Arqueología Americana* (6), 91-124.

- Chandler-Ezell, K. and Pearsall, D., 2003. Piggyback microfossil processing: joint starch and phytolith sampling from stone tools *The Phytolitharien: Bulletin of the Society for Phytolith Research* 15(3), 2-8.
- Chandler-Ezell, K., Pearsall, D. and Zeidler, J.A., 2006. Root and tuber phytoliths and starch grains document Manioc (*Manihot esculenta*), Arrowroot (*Maranta arundinacea*), and Llerén (*Calathea* sp.) at the Real Alto Site, Ecuador. *Economic Botany* 60(2), 103-120.
- Chevalier, A., 2002. L'exploitation des plantes sur la côte péruvienne en contexte Formatit ("The exploitation of plants on the Peruvian coast in Formative Context"). Unpublished PhD thesis, University of Geneva.
- Chevalier, A., 2008. Early Holocene human adaptation in the Central Andes: What the phytoliths can tell us? In: M.A. Korstanje & M.P. Babot (eds.), *Matices interdisciplinarios en estudios fitolíticos y de otros microfósiles*. Oxford: Hedges, 149-162.
- Childe, G.V., 1951. *Man makes himself*. New York: New American Library.
- Clement, C., 1999. 1942 and the Loss of Amazonian Crop Genetic Resources. I. The Relation between Domestication and Human Population Decline. *Economic Botany* 53(2), 188-202.
- Clement, C., 2006. Fruit trees and the transition to food production in the Amazonia. In: C.L.E. William Balée (ed.), *Time and Complexity in Historical Ecology: Studies in the Neotropical Lowlands*. New York: Columbia University Press, 165-185.
- Cohen, M., 1977. Population pressure and the origins of agriculture. An archaeological example from the Coast of Peru. In: C.A. Reed (ed.), *Origins of agriculture*. The Hague: Mouton, 135-177.
- Cohen, M., 1978. Archaeological plant remains from the central coast of Peru. *Nawpa Pacha* 16, 23-50.

- Coil, J., Korstanje, M.A., Archer, S. and Hastorf, C., 2003. Laboratory goals and considerations for multiple microfossil extraction in archaeology. *Journal of Archaeological Science* 30(8), 991-1008.
- Colson, E., 1979. The Harvey Lecture Series. In good years and in bad: food strategies of self-reliant societies. *Journal of Anthropological Research* 35(1), 18-29.
- Coltrain, J.B., Janetski, J.C. and Shawn, C.W., 2006. The stable and radio-isotope chemistry of eastern Basketmaker and Pueblo groups in the four corners region of the American Southwest: implications for Anasazi diets, origins, and abandonments in Southwestern Colorado. In: J. Staller, R. Tykot & B.F. Benz (eds.), *Histories of maize: multidisciplinary approaches to the prehistory, linguistics, biogeography, domestication and evolution of maize*. Amsterdam: Elsevier, 276-285.
- Consecol, C., 1988. Diagnóstico agrícola de la provincia del Loa. Antofagasta: Secretaría Regional Ministerial de planificación y coordinación II Región.
- Contreras, E., 1994. Cultura y naturaleza en la cuenca del Salar de Atacama. *Estudios Atacameños* 11, 179-184.
- Cordain, L., Miller, J.B., Eaton, S.B., Mann, N., Holt, S.H. and Speth, J.D., 2000. Plant-animal subsistence ratios and macronutrient energy estimations in worldwide hunter-gatherer diets. *American Journal of Clinical Nutrition* 71(3), 682-692.
- Córdoba, A.M., N.D. *Informe Final del Proyecto Nacional INTA 520403. Conservación y Mejoramiento del Algarrobo en el Chaco Árido Argentino* [online]. Instituto Nacional de Tecnología Agropecuaria Available from:
<http://redaf.org.ar/noticias/wp-content/uploads/2008/02/El-Cultivo-del-Algarrobo.pdf>.
 [Accessed 6 February 2013]
- Cornejo, L., 1990. La molienda en el Pukara de Turi. *Chungara* 24/25, 125-144.
- Cortella, A.R. and Pochettino, M.L., 1990. South American grain chenopods and maranth: a comparative morphology of starch. *Starch - Stärke* 42(7), 251-255.

- Cortella, A.R. and Pochettino, M.L., 1994. Starch grain analysis as a microscopic diagnostic feature in the identification of plant material. *Economic Botany* 48(2), 171-181.
- Cortella, A.R. and Pochettino, M.L., 1995. Comparative morphology of starch of three Andean tubers. *Starch - Stärke* 47(12), 455-461.
- Cortella, A.R., Pochettino, M.L., Manzo, A. and Raviña, G., 2001. Erythroxylum coca: microscopical identification in powdered and carbonized archaeological material. *Journal of Archaeological Science* 28(8), 787-794.
- Costa, M., Neves, W. and Hubbe, M., 2004. Influencia de Tiwanaku en la calidad de vida biológica de la población prehistórica de San Pedro de Atacama. *Estudios Atacameños* 27, 103-116.
- Custred, G., 1977. Las punas de los Andes centrales. In: J. Flores Ochoa (ed.), *Pastores de Puna: Uywamichiq Punarunakuna*. Lima: Instituto de Estudios Peruanos, 55-86.
- D'antoni, H. and Solbrig, O., 1977. Algarrobos in South American cultures past and present. *US/IBP Synthesis Series* 4, 189-199.
- Damp, J.E. and Pearsall, D., 1994. Early cotton from coastal Ecuador. *Economic Botany* 48(2), 163-165.
- Danielson, D.R. and Reinhard, K.J., 1998. Human dental microwear caused by calcium oxalate phytoliths in prehistoric diet of the lower Pecos region, Texas. *American Journal of Physical Anthropology* 107(3), 297-304.
- Dauelsberg, P., 1985. Faldas del Morro. Fase cultural Agro-alfarera Temprana. *Chungara* 14, 7-44.
- De Candolle, A., 1884. *Origin of cultivated plants*. London: Kegan Paul, Trench & Co.
- De Rosales, D., 1877. *Historia General del Reino de Chile, Flandes Indiano*. Valparaíso.
- Delfino, D., Espiro, V. and Díaz, A., 2009. Modos de vida situados: el Formativo en Laguna Blanca. *Andes* 20, 111-134.

- Demaio, P., 1988. Árboles nativos de Córdoba. *Aquí Vivimos* 1(Special Issue).
- Dickau, R., Ranere, A.J. and Cooke, R.G., 2007. Starch Grain Evidence for the Preceramic Dispersals of Maize and Root Crops into Tropical Dry and Humid Forests of Panama. *Proceedings of the National Academy of Sciences* 104(9), 3651-3656.
- Dillehay, T. (ed.) 2011. *From foraging to farming in the Andes: new perspectives on food production and social organization*, New York: Cambridge University Press.
- Dillehay, T., Rossen, J., Andres, T. and Williams, D., 2007. Preceramic Adoption of Peanut, Squash, and Cotton in Northern Peru. *Science* 316(5833), 1890-1893.
- Dillehay, T., Rossen, J. and Netherly, P., 1997. The Nanchoc Tradition: The Beginnings of Andean Civilization: Seven thousand years ago, in northern Peru, the processing of lime, most likely for use with coca, launched a community toward social complexity. *American Scientist* 85(1), 46-55.
- Dillehay, T., Rossen, J. and Stackelbeck, K., 2011. Foraging to farming and community development. In: T. Dillehay (ed.), *From foraging to farming in the Andes: new perspectives on food production and social organization*. New York: Cambridge University Press, 257-274.
- Dillehay, T., Rossen, J., Ugent, D., Karathanasis, A., Vásquez, V. and Netherly, P., 2010. Early Holocene coca chewing in northern Peru. *Antiquity* 84(326), 939-953
- Dodd, R.J. and Stanton, R.J., 1990. *Paleoecology, concepts and applications*. New York: Wiley.
- Doebley, J., 1990. Molecular Evidence and the Evolution of Maize. *Economic Botany* 44(3), 6-27.
- Douglas, M., 1972. Deciphering a meal. *Daedalus* 101(1), 61-81.
- Dransart, P., 1991. Llamas, Herders and the Exploitation of Raw Materials in the Atacama Desert. *World Archaeology* 22(3), 304-319.

- Dransart, P., 2002. *Earth, water, fleece and fabric: an ethnography and archaeology of Andean camelid herding*. London: Routledge.
- Drennan, R., 1996. Betwixt and between in the Intermediate Area. *Journal of Archaeological Research* 4(2), 95-131.
- Druss, M., 1976. Medioambiente, economia de subsistencia y patrones de asentamiento del Complejo Chiu Chiu (ca. 3.000- 2.000BC), Norte de Chile. *Estudios Atacameños* 4, 17-23.
- Duncan, N., Pearsall, D. and Benfer, R., 2009. Gourd and squash artifacts yield starch grains of feasting foods from preceramic Peru. *Proceedings of the National Academy of Sciences* 106(32), 13202-13206.
- Eaton, S.B., Eaton, S.B.I. and Konner, M.J., 1997. Paleolithic nutrition revisited: a twelve-year retrospective on its nature and implications. *European Journal of Clinical Nutrition* 51(4), 207-216.
- Eaton, S.B., Eaton, S.B.I., Konner, M.J. and Shostak, M., 1996. An evolutionary perspective enhances understanding of human nutritional requirements. *The Journal of Nutrition* 126(6), 1732-1740.
- Eaton, S.B. and Konner, M.J., 1985. Paleolithic nutrition. A consideration of its nature and current implications. *New England Journal of Medicine* 312(5), 283-289.
- Ehleringer, J.R., Mooney, H.A., Rundel, P.W., Evans, D.R., Palma, B. and Delatorre, J., 1992. Lack of nitrogen cycling in the Atacama Desert. *Nature* 359(6393), 316-318.
- Ehleringer, J.R., Rundel, P.W., Palma, B. and Mooney, H.A., 1998. Carbon isotope ratios of Atacama Desert plant reflect hyperaridity of region in northern Chile. *Revista Chilena de Historia Natural* 71, 78-86.
- Eisentraut, P.J., 1998. Macrobotanical remains from southern Peru: A comparison of Late Archaic-Early Formative period sites from the Puna and Suni zones of the Western Titicaca basin. Unpublished PhD thesis, University of California at Santa Barbara.

- Erices, S., 1975. Evidencias de vegetales en tres cementerios prehispánicos, Arica - Chile. *Chungara* 5, 65-71.
- Erickson, D.L., Smith, B.D., Clarke, A.C., Sandweiss, D.H. and Tuross, N., 2005. An Asian origin for a 10,000-year-old domesticated plant in the Americas. *Proceedings of the National Academy of Sciences* 102(51), 18315-18320.
- Escola, P., 1996. Riesgo e incertidumbre en economías agropastoriles: consideraciones teórico-metodológicas. *Arqueología* 6, 9-24.
- Evans, D.R. and Ehleringer, J.R., 1994. Plant $\delta^{15}\text{N}$ values along a fog gradient in the Atacama Desert, Chile. *Journal of Arid Environments* 28(3), 189-193.
- Falabella, F., Planella, M.T., Aspillaga, E., Sanhueza, L. and Tykot, R.H., 2007. Dieta en sociedades alfareras de Chile Central: aportes de análisis de isótopos estables. *Chungara* 39(1), 5-27.
- Farrington, I.S. and Urry, J., 1985. Food and the early history of cultivation. *Journal of Ethnobiology* 5(2), 143-157.
- Felker, P. and Ydeberg, C., 1995. *Prosopis alba* and *Prosopis chilensis*: Subtropical semiarid fuel and fodder trees [online]. Forest, Farm, and Community Tree Network (FACT Net). Available from:
http://www.winrock.org/fnrm/factnet/factpub/FACTSH/P_alba.html
- [Accessed 22 september 2010]
- Fernández De Oviedo Y Valdés, G., 1851. *Historia general y natural de Las Indias, islas y tierra-firme del mar océano*. Madrid: Imprenta de la Real Academia de la Historia.
- Fernández Distel, A., 1999. El maíz, origen de su cultivo en Sudamérica. *Revista del Centro de Estudios Antropológicos, Suplemento Antropológico* 34(1), 81-100.
- Fernández, J., Markgraff, V., Panarello, H.O., Albero, M.C., Angiolini, F.E., Valencio, S. and Arriaga, M., 1991. Late Pleistocene/ Early Holocene Environments and Climates,

- Fauna, and Human Occupation in the Argentine Altiplano. *Geoarchaeology* 6(3), 251-272.
- Fernández, J. and Panarello, H.O., 1988-1990. Paleodietas y patrones de movilidad de cazadores recolectores: su estimación en base a los isótopos estables del carbono. Arqueología de los Pinares Cordilleranos del Neuquén. *Anales de Arqueología y Etnología* 43-45, 599-611.
- Fernández, M., Zucol, A. and Osterrieth, M., 2009. Phytolith analysis of Cyperaceae from the Pampean region, Argentina. *Australian Journal of Botany* 57 512-523.
- Ferreira De Mattos, G.A., 2006. *Silvopastoral Systems in Latin America* [online]. Society of American foresters, International Society of American Foresters. Available from: <http://wiki.safnet.org/index.php/Forestman15>. [Accessed 14 April 2013]
- Field, J. and Fullagar, R., 1998. Grinding and pounding stones from Cuddie Springs and Jinmium. In: R. Fullagar (ed.), *A closer look: recent Australian studies of stone tools*. Sydney: University of Sydney, 95-108.
- Figueroa, G. and Dantas, M., 2006. Recolección, procesamiento y consumo de frutos silvestres en el noroeste semiárido argentino. Casos actuales con implicancias arqueológicas. *La Zaranda de Ideas* 2, 35-50.
- Finucane, B., Agurto, P.M. and Isbell, W.H., 2006. Human and animal diet at Conchopata, Peru: stable isotope evidence for maize agriculture and animal management practices during the Middle Horizon. *Journal of Archaeological Science* 33(12), 1766-1776.
- Flannery, K.V., 1968. Archaeological systems theory and Early Mesoamerica. In: B. Meggers (ed.), *Anthropological archaeology in the Americas*. Washington: Anthropological Society of Washington, 67-87.

- Flannery, K.V., 1969. Origins and the ecological effects of early domestication in Iran and the Near East. In: P.J. Ucko & G.W. Dimbleby (eds.), *The domestication and exploitation of plants and animals*. London: Duckworth, 73-100.
- Focacci, G., 1974. Excavaciones en el cementerio Playa Miller 7, Arica (Chile). *Chungara* 3, 23-74.
- Ford, J., 1969. *A comparison of formative of cultures in the Americas*. Washington DC: Smithsonian Institution Press.
- Ford, R.I., 1985. The processes of plant food production in prehistoric North America. In: R.I. Ford (ed.), *Prehistoric food production in North America*. Ann Arbor: Museum of Anthropology, University of Michigan, 1-18.
- Fox, J., 2007. Time and Process in an Early Village Settlement System on the Bolivian Southern Altiplano. Unpublished PhD thesis, University of Pittsburgh.
- Franceschi, V. and Horner, H., 1980. Calcium oxalate crystals in plants. *Botanical Review* 46(4), 361-427.
- Fredlund, G.G. and Tieszen, L.L., 1994. Modern phytolith assemblages from the North American Great Plains. *Journal of Biogeography* 21, 321-335.
- Fritz, G., 1994. Are the First American Farmers Getting Younger? *Current Anthropology* 35(3), 305-309.
- Fuentes, F. and Bhargava, A., 2011. Morphological Analysis of Quinoa Germplasm Grown Under Lowland Desert Conditions. *Journal of Agronomy and Crop Science* 197(2), 124-134.
- Fuller, D., 2007. Contrasting Patterns in Crop Domestication and Domestication Rates: Recent Archaeobotanical Insights from the Old World. *Annals of Botany* 100(5), 903-924.

- Galera, F.M., 2000. *Los Algarrobos. Las especies del género Prosopis (algarrobos) de América Latina con especial énfasis en aquellas de interés económico*. Córdoba: UNC-Secretaría de Ciencia y Tecnología; FAO.
- Gas Bench Ii, 1999-2013. *Methodology for analysis on the UCL Gas Bench* [online]. <http://www.ucl.ac.uk/beif/method-files>. [Accessed 4 May 2013]
- Gayo, E.M., Latorre, C., Jordan, T.E., Nester, P.L., Estay, S.A., Ojeda, K.F. and Santoro, C., 2012b. Late Quaternary hydrological and ecological changes in the hyperarid core of the northern Atacama Desert (21°S). *Earth-Science Reviews* 113(3–4), 120-140.
- Gayo, E.M., Latorre, C., Santoro, C., Maldonado, A. and De Pol-Holz, R., 2012a. Hydroclimate variability in the low-elevation Atacama Desert over the last 2500 yr. *Climate of the Past* 8, 287-306.
- Gepts, P., 1990. Biochemical Evidence Bearing on the Domestication of Phaseolus (Fabaceae) Beans. *Economic Botany* 44(3), 28-38.
- Geyh, M.A., Grosjean, M., Núñez, L. and Schotterer, U., 1999. Radiocarbon Reservoir Effect and the Timing of the Late-Glacial/Early Holocene Humid Phase in the Atacama Desert (Northern Chile). *Quaternary Research* 52(2), 143-153.
- Gil, A.F., Neme, G.A., Tykot, R.H., Novellino, P., Cortegoso, V. and Durán, V., 2009. Stable isotopes and maize consumption in central western Argentina. *International Journal of Osteoarchaeology* 19(2), 215-236.
- Giovannetti, M.A., Lema, V.S., Bartoli, C.G. and Capparelli, A.M., 2008. Starch grain characterization of *Prosopis chilensis* (Mol.) Stuntz and *P. flexuosa* DC, and the analysis of their archaeological remains in Andean South America. *Journal of Archaeological Science* 35(11), 2973-2985.
- Goland, C., 1993. Field scattering as agricultural risk management: A case study from Cuyo, Department of Puno, Perú. *Mountain Research and Development* 13(4), 317-338.

- Golte, J., 2001. *Cultura, racionalidad y migración Andina*. Lima: Instituto de Estudios Peruanos.
- González, C. and Westfall, C., 2006. Cementerio regimiento Chorrillos de Calama: testimonios funerarios Formativos en el Loa Medio, región de Antofagasta. *Actas del XVII Congreso Nacional de Arqueología Chilena*. Universidad Austral, Valdivia: SCHA, 95-105.
- Grace, R., 1996. Use-wear analysis: the state of the art. *Archaeometry* 38(2), 209-229.
- Gremillion, K.J., 1996a. Diffusion and adoption of crops in evolutionary perspective. *Journal of Anthropological Archaeology* 15(2), 183-204.
- Gremillion, K.J., 1996b. Early Agricultural Diet in Eastern North America: Evidence from Two Kentucky Rockshelters. *American Antiquity* 61(3), 520-536.
- Grosjean, M., Cartajena, I., Geyh, M.A. and Nuñez, L., 2003. From proxy data to paleoclimate interpretation: the mid-Holocene paradox of the Atacama Desert, northern Chile. *Palaeogeography, Palaeoclimatology, Palaeoecology* 194(1-3), 247-258.
- Grosjean, M., Nuñez, L., Cartajena, I. and Messerli, B., 1997. Mid-Holocene climate and culture change in the Atacama Desert, northern Chile. *Quaternary Research* 48(2), 239-246.
- Grosjean, M., Van Leeuwen, J., Van Der Knaap, W.O., Geyh, M.A., Ammann, B., Tinner, W., Messerli, B., Nuñez, L., Valero-Garcés, B. and Veit, H., 2001. A 22,000 14C year BP sediment and pollen record of climate change from Laguna Miscanti (23°S), northern Chile. *Global and Planetary Change* 28(1-4), 35-51.
- Grun, P., 1990. The evolution of cultivated potatoes. *Economic Botany* 44(3), 39-55.
- Guillet, D., 1987. On the potential for intensification of agropastoralism in the arid zones of the central Andes. In: D. Browman (ed.), *Arid land use strategies and risk management in the Andes A regional anthropological perspective*. Boulder: Westview Press, 81-98.

- Gunckel, H., 1967. Fitonimia Atacameña, especialmente cunza. *Revista Universitaria Universidad Católica de Chile* 52, 3-81.
- Gundermann, H. and González, H., 1995. Tierra, agua y sociedad Atacameña. Un territorio cambiante. In: P. Pourrot & L. Núñez (eds.), *Agua, ocupación del espacio y economía campesina en la región atacameña. Aspectos dinámicos*. Antofagasta: Universidad Católica del Norte - ORSTOM., 78-106.
- Gurfinkel, D.M. and Franklin, U.M., 1988. A study of the feasibility of detecting blood residue on artifacts. *Journal of Archaeological Science* 15(1), 83-97.
- Gutiérrez, F., 2004. *Primera aproximación al contexto lítico de molienda del sitio Tulan 54*. Proyecto Fondecyt 1020316. Unpublished report.
- Haber, A.F. and Gastaldi, M.R., 2006. Vida con palas. *Antípoda* 2, 275-302.
- Halstead, P., 1989. The economy has a normal surplus: Economic stability and social change among early farming communities of Thessaly, Greece. In: P. Halstead & J. O'shea (eds.), *Bad year economics: cultural responses to risk and uncertainty*. Cambridge: Cambridge University Press, 68-80.
- Harlan, J.R., 1971. Agricultural origins: centers and noncenters. *Science* 174(4008), 468-474.
- Harlan, J.R., 1975. *Crops and man*. Madison: American Society of Agronomy.
- Harris, D., 1969. Agricultural systems, ecosystems and the origins of agriculture. In: P.J. Ucko & G.W. Dimbleby (eds.), *The domestication and exploitation of plants and animals*. London: Duckworth, 3-14.
- Harris, D., 1989. An evolutionary continuum of people-plant interaction. In: D.R. Harris & G.C. Hillman (eds.), *Foraging and farming: the evolution of plant exploitation*. London: Unwin Hyman, 11-24.
- Harris, D., 1996. Domesticatory relations of people, plants and animals. In: R. Ellen, And Fukui, K. (ed.), *Redefining Nature*. Oxford, 437-463.

- Harris, D., 1996a. Introduction: themes and concepts in the study of early agriculture. In: D. Harris (ed.), *The Origins and Spread of Agriculture and Pastoralism in Eurasia*. Washington, DC: Smithsonian Institution Press, 1-11.
- Harris, D., 1996b. *The origins and spread of agriculture and pastoralism in Eurasia*. Washington DC: Smithsonian Institution Press.
- Harris, D., 2007. An evolutionary continuum of people-plant interaction (1989). In: T. Denham & P. White (eds.), *The emergence of agriculture: a global view*. New York: Routledge, 50-76.
- Harrison, R.G. and Katzenberg, M.A., 2003. Paleodiet studies using stable carbon isotopes from bone apatite and collagen: examples from Southern Ontario and San Nicolas Island, California. *Journal of Anthropological Archaeology* 22(3), 227-244.
- Harrison, R.J., 1996. Aborigiculture in Southwest Europe: dehesas as managed woodlands. In: D. Harris (ed.), *The origins and spread of agriculture and pastoralism in Eurasia*. Washington, DC: Smithsonian Institution Press, 363-369.
- Hart, T., 2011. Evaluating the usefulness of phytoliths and starch grains found on survey artifacts. *Journal of Archaeological Science* 38(12), 3244-3253.
- Haslam, M., 2004. The decomposition of starch grains in soils: implications for archaeological residue analyses. *Journal of Archaeological Science* 31(12), 1715-1734.
- Haslam, M., 2009. Mountains and molehills: sample size in archaeological microscopic stone-tool residue analysis. In: M. Haslam, G. Robertson, A. Crowther, S. Nugent & L. Kirkwood (eds.), *Archaeological science under a microscope: studies in residue and ancient DNA analysis in honour of Thomas H. Loy*. Canberra: ANU E Press, 47-79.
- Hastorf, C., 1987. Archaeological Evidence of Coca (*Erythroxylum coca*, Erythroxylaceae) in the Upper Mantaro Valley, Peru. *Economic Botany* 41(2), 292-301.

- Hastorf, C., 1991. Gender, space, and food in prehistory. In: J. Gero & M. Conkey (eds.), *Engendering archaeology: women and prehistory*. Oxford: Blackwell, 132-159.
- Hastorf, C., 1999. Cultural implications of crop introductions in Andean prehistory. In: C. Gosden & J. Hather (eds.), *The prehistory of food: appetites for change*. London; New York: Routledge, 33-56.
- Hastorf, C., 2003. Community with the ancestors: ceremonies and social memory in the Middle Formative at Chiripa, Bolivia. *Journal of Anthropological Archaeology* 22(4), 305-332.
- Hastorf, C., 2006. Domesticated food and society in Early Coastal Peru. In: W. Balée & C. Erickson (eds.), *Time and Complexity in Historical Ecology: Studies in the Neotropical Lowlands*. New York: Columbia University Press, 87-126.
- Hastorf, C., 2009. Rio Balsas most likely region for maize domestication. *Proceedings of the National Academy of Sciences* 106(13), 4957-4958.
- Hastorf, C. and Johannessen, S., 1993. Pre-Hispanic Political Change and the Role of Maize in the Central Andes of Peru. *American Anthropologist* 95(1), 115-138.
- Hather, J., 1994. A Morphological Classification of Roots and Tubers and its bearing on the Origins of Agriculture in Southwest Asia and Europe. *Journal of Archaeological Science* 21(6), 719-724.
- Hather, J.G., 2000. *Archaeological parenchyma*. London: Archetype.
- Hawkes, J.G., 1989. The domestication of roots and tubers in the American tropics. In: D.R. Harris & G.C. Hillman (eds.), *Foraging and farming: the evolution of plant exploitation*. London: Unwin Hyman, 481-503.
- Hawkes, J.G., 1990. *The potato: evolution, biodiversity and genetic resources*. Washington DC: Smithsonian Institution Press.

- Hayden, B., 1990. Nimrods, piscators, pluckers, and planters: the emergence of food production. *Journal of Anthropological Archaeology* 9(1), 31-69.
- Hayden, B., 1995. A new overview of domestication. In: T.D. Price & A.B. Gebauer (eds.), *Last hunters, first farmers: new perspectives on the prehistoric transition to agriculture*. Santa Fe: School of American Research Press, 273-300.
- Heiser, C., 1965. Cultivated plants and cultural diffusion in nuclear America. *American Anthropologist* 67(4), 930-949.
- Heiser, C., 1978. The Totorá (*Scirpus californicus*) in Ecuador and Peru. *Economic Botany* 32(3), 222-236.
- Heiser, C., 1985. *Of plants and people*. Norman: University of Oklahoma Press.
- Heiser, C., 1989. Domestication of Cucurbitaceae: Cucurbita and Lagenaria. In: D.R. Harris & G.C. Hillman (eds.), *Foraging and farming: the evolution of plant exploitation*. London: Unwin Hyman, 471-480.
- Hesse, B., 1982a. Archaeological evidence of camelid exploitation in the Chilean Andes. *Säugetierkundliche Mitteilungen* 30(2), 201-211.
- Hesse, B., 1982b. Animal domestication and oscillating climates. *Journal of Ethnobiology* 2(1), 1-15.
- Hesse, B., 1984. Archaic exploitation of small mammals and birds in Northern Chile. *Estudios Atacameños* 4, 42-61.
- Hesse, B., 1986. Buffer resources and animal domestication in prehistoric northern Chile. In: P. Ducos (ed.), *Archaeozoologia: mélanges publiés à l'occasion du 5e Congrès International d'Archéozoologie*. Grenoble: La Pensée Sauvage, 73-85.
- Heusser, C.J., 1971. *Pollen and spores of Chile: modern types of the Pteridophyta, Gymnospermae, and Angiospermae*. Tucson: University of Arizona Press.

- Hevly, R.H., 1964. Pollen Analysis of Quaternary Archaeological and Lacustrine Sediments from the Colorado Plateau. Unpublished PhD thesis, University of Arizona.
- Hidalgo, J., 1984. Complementariedad ecológica y tributo en Atacama (1683-1792). *Estudios Atacameños* 7, 311-325.
- Hidalgo, J., 1985. Ecological complementarity and tribute in Atacama: 1683-1792. In: S. Masuda, I. Shimada & C. Morris (eds.), *Andean Ecology and Civilization*. Tokio: Tokio Press, 161-184.
- Hidalgo, J., 1992. Organización social, tradición y aculturación de Socaire, una aldea Atacameña. Universidad de Chile.
- Hidalgo, J., 2004. *Historia Andina en Chile*. Santiago: Editorial Universitaria.
- Higgs, E.S., 1972. The origins of animal and plant husbandry. In: E.S. Higgs (ed.), *Papers in Economic Prehistory*. Cambridge: Cambridge University Press, 3-15.
- Hocsman, S., 2002. ¿Cazadores-recolectores complejos en la puna meridional argentina? Entrelazando evidencias del registro arqueológico de la microrregión de Antofagasta de la Sierra (Catamarca). *Relaciones de la Sociedad Argentina de Antropología* 27, 193-214.
- Hocsman, S., 2006. Tecnología lítica en la transición de cazadores recolectores a sociedades agropastoriles en la porción meridional de los Andes Centro Sur. *Estudios Atacameños* 32, 59-73.
- Holden, T., 1991. Evidence of prehistoric diet from northern Chile: coprolites, gut contents and flotation samples from Tulan Quebrada. *World Archaeology* 22(3), 320-331.
- Holmgren, C., Betancourt, J., Rylander, K., Roque, J., Tovar, O., Zeballos, H., Linares, E. and Quade, J., 2001. Holocene vegetation history from fossil rodent middens near Arequipa, Peru. *Quaternary Research* 56(2), 242-251.

- Horta, H., 2012. El estilo Circumpuneño en el arte de la parafernalia alucinógena prehispánica (Atacama y Noroeste Argentino). *Estudios atacameños* 5-34.
- Hughes, C.E., Govindarajulu, R., Robertson, A., Filer, D.L., Harris, S.A. and Bailey, D.C., 2007. Serendipitous backyard hybridization and the origin of crops. *Proceedings of the National Academy of Sciences* 104(36), 14389-14394.
- Ittis, H., 2006. Origin of polystichy in maize. In: J. Staller, R. Tykot & B.F. Benz (eds.), *Histories of maize: multidisciplinary approaches to the prehistory, linguistics, biogeography, domestication and evolution of maize*. Amsterdam: Elsevier, 21-53.
- Iriarte, J., Holst, I., López, J.M. and Cabrera, L., 2001. Subtropical wetland adaptations in Uruguay during the Mid-Holocene: an archaeobotanical perspective. In: B. Purdy (ed.), *Enduring records: the environmental and cultural heritage of wetlands*. London: Oxbow Books, 61-70.
- Iriarte, J. and Paz, E.A., 2009. Phytolith analysis of selected native plants and modern soils from southeastern Uruguay and its implications for paleoenvironmental and archeological reconstruction. *Quaternary International* 193(1-2), 99-123.
- Izeta, A.D., Laguens, A.G., Marconetto, M.B. and Scattolin, M.C., 2009. Camelid handling in the meridional Andes during the first millennium AD: a preliminary approach using stable isotopes. *International Journal of Osteoarchaeology* 19(2), 204-214.
- Jackson, D. and Benavente, A., 1994. Secuencia, cambios y adaptación de los cazadores-recolectores de la microcuenca de Chiu-Chiu, Provincia del Loa. *Chungara* 26(1), 49-64.
- Jackson, D. and Benavente, A., 1995. Instrumentos líticos del complejo pastoril temprano «Chiuchiu 200», norte de Chile. *Estudios Atacameños* 12, 41-52.
- Jackson, D. and Benavente, A., 2010. Complejización de los cazadores y recolectores en Chiu Chiu, río Loa Medio (norte de Chile). *Estudios Atacameños* 39, 5-20.

- Jarman, M., Bailey, G. and Jarman, H., 1982. *Early European agriculture: its foundation and development*. Cambridge: Cambridge University Press.
- Jenkins, E. and Rosen, A., 2007. The phytoliths. In: B. Finlayson & S.J. Mithen (eds.), *The Early Prehistory of Wadi Faynan, Southern Jordan: Archaeological Survey of Wadis Faynan, Ghuwayr and Al-Bustan and Evaluation of the Pre-Pottery Neolithic A Site of WF16*. Levant: Oxbow Books, Limited.
- Johannessen, S. and Hastorf, C. (eds.) 1994. *Corn and Culture in the Prehistoric New World*, Boulder: Westview Press.
- Johns, T., 1989. A chemical-ecological model of root and tuber domestication in the Andes. In: D. Harris & G. Hillman (eds.), *Foraging and farming. The evolution of plant exploitation*. London: Unwin Hyman, 504-517.
- Kalin-Arroyo, M., Squeo, F., Armesto, J. and Villagran, C., 1988. Effects of aridity on plant diversity in the Northern Chilean Andes: results of a natural experiment. *Annals of the Missouri Botanical Garden* 75(1), 55-78.
- Kaplan, L.T. and Lynch, T., 1999. Phaseolus (Fabaceae) in archaeology: AMS radiocarbon dates and their significance for Pre-Columbian agriculture. *Economic Botany* 53(3), 261-272.
- Kattermann, F., 2011. Observations of the Chilean Opuntioideae. *Cactus and Succulent Journal* 83(4), 150-162.
- Kealhofer, L., Torrence, R. and Fullagar, R., 1999. Integrating Phytoliths within Use-Wear/Residue Studies of Stone Tools. *Journal of Archaeological Science* 26(5), 527-546.
- Kelly, J., Tykot, R. and Milanich, J., 2006. Evidence for early use of maize in peninsular Florida. In: J. Staller, R. Tykot & B.F. Benz (eds.), *Histories of maize: multidisciplinary approaches to the prehistory, linguistics, biogeography, domestication and evolution of maize*. Amsterdam: Elsevier, 249-261.

- Kelly, R.L., 1992. Mobility/Sedentism: Concepts, Archaeological Measures, and Effects. *Annual Review of Anthropology* 21, 43-66.
- Knudson, K., 2008. Tiwanaku Influence in the South Central Andes: Strontium Isotope Analysis and Middle Horizon Migration. *Latin American Antiquity* 19(1), 3-23.
- Knudson, K., 2009. Oxygen isotope analysis in a land of environmental extremes: the complexities of isotopic work in the Andes. *International Journal of Osteoarchaeology* 19(2), 171-191.
- Knudson, K., Pestle, W., Torres-Rouff, C. and Pimentel, G., 2012. Assessing the life history of an andean traveller through biogeochemistry: Stable and radiogenic isotope analyses of archaeological human remains from Northern Chile. *International Journal of Osteoarchaeology* 22(4), 435-451.
- Knudson, K., Price, T., Buikstra, J. and Blom, D., 2004. The use of strontium isotopes analysis to investigate Tiwanaku migration and mortuary ritual in Bolivia and Peru. *Archaeometry* 46(1), 5-18.
- Knudson, K. and Torres-Rouff, C., 2009. Investigating cultural heterogeneity in San Pedro de Atacama, northern Chile, through biogeochemistry and bioarchaeology. *American Journal of Physical Anthropology* 138(4), 473-485.
- Korstanje, A., 2001a. *Andean Phytolith Reference Collection*. Berkeley. Unpublished report.
- Korstanje, A., 2001b. Microfossils in camelid dung: taphonomic considerations for the archaeological study of agriculture and pastoralism. In: T. O'connor (ed.), *Biosphere to lithosphere: new studies in vertebrate taphonomy*. Oxford: Oxbow Books, 70-78.
- Korstanje, A., 2005. La organización del trabajo en torno a la producción de alimentos en sociedades agro-pastoriles Formativas (Provincia de Catamarca, Argentina). Unpublished PhD thesis, Universidad Nacional de Tucumán.

- Korstanje, A. and Babot, M.D.P., 2007. Microfossils characterization from south Andean economic plants. In: M. Madella & D. Zurro (eds.), *Plants, people and places: recent studies in phytolith analysis*. Oxford: Oxbow Books, 41-72.
- Korstanje, A. and Würschmidt, A., 1999. Producir y recolectar en los valles altos del NOA: “Los Viscos” como caso de estudio. In: C.A. Aschero, A. Korstanje & P. Vuoto (eds.), *En los tres reinos: prácticas de recolección en el Cono Sur de América*. Tucumán: Instituto de Arqueología y Museo, Facultad de Ciencias Naturales e Instituto Miguel Lillo, Universidad Nacional de Tucumán, 151-160.
- Kraus, R., Trimborna, P. and Zieglerbc, H., 2001. $\delta^{13}\text{C}$ and δD Values of *Opuntia atacamensis* depending on different environmental conditions in the Atacama Desert of northern Chile. *Isotopes in Environmental and Health Studies* 37 (2), 161-165.
- Kroeber, A.L., 1930. Cultural relations between North and South America *Proceedings of the 23rd International Congress of Americanists (1928)*. New York, 5-22.
- Kuznar, L., 1993. Mutualism between *Chenopodium*, Herd Animals, and Herders in the South Central Andes. *Mountain Research and Development* 13(3), 257-265.
- Kuznar, L., 2001. Risk Sensitivity and Value among Andean Pastoralists: Measures, Models, and Empirical Tests. *Current Anthropology* 42(3), 432-440.
- Labarca, R., 2005. Zooarqueología de fauna menor en la Puna Salada: El caso de Quebrada Tulán (II Región, Chile). Unpublished undergraduate thesis, Universidad de Chile.
- Laguens, A.G., 1999. La recolección de la algarroba en la economía indígena del Norte de Córdoba. In: C. Aschero, M.A. Korstanje & P. Vuoto (eds.), *En los tres reinos: prácticas de recolección en el Cono Sur de América*. Tucumán: Instituto de Arqueología y Museo, Facultad de Ciencias Naturales e Instituto Miguel Lillo, Universidad Nacional de Tucumán, 187-196.
- Lamarque, A., Maestri, D., Zygodlo, J. and Guzman, C., 2000. Chemical evaluation of *Geoffroea decorticans* seeds as source of oil and protein. *Grasas y Aceites* 51, 241-243.

- Langejans, G., 2010. Remains of the day-preservation of organic micro-residues on stone tools. *Journal of Archaeological Science* 37(5), 971-985.
- Langejans, G., 2011. Discerning use-related micro-residues on tools: testing the multi-stranded approach for archaeological studies. *Journal of Archaeological Science* 38(5), 985-1000.
- Langlie, B.S., Hastorf, C., Bruno, M.C., Bermann, M., Bonzani, R.M. and Condarco, W.C., 2011. Diversity In Andean Chenopodium Domestication: Describing A New Morphological Type From La Barca, Bolivia 1300-1250 B.C. *Journal of Ethnobiology* 31(1), 72-88.
- Lanning, E.P., 1967. *Peru before the Incas*. Englewood Cliffs: Prentice-Hall.
- Latcham, R., 1936a. Indian ruins in Northern Chile. *American Anthropologist* 38(1), 52-58.
- Latcham, R., 1936b. *La agricultura precolombina en Chile*. Santiago: Universidad de Chile.
- Lathrap, D., 1970. *Upper Amazon*. London: Thames & Hudson.
- Lathrap, D., 1973. The Antiquity and Importance of Long-Distance Trade Relationships in the Moist Tropics of Pre-Columbian South America. *World Archaeology* 5(2), 170-186.
- Lathrap, D., 1977. Our father the cayman, our mother the gourd: Spinden revisited, or a unitary model for the emergence of agriculture in the New World. In: C.A. Reed (ed.), *Origins of agriculture*. The Hague: Mouton, 713-751.
- Latorre, C., Betancourt, J. and Kalin-Arroyo, M., 2006. Late Quaternary vegetation and climate history of a perennial river canyon in the Río Salado basin (22°S) of northern Chile. *Quaternary Research* 65(3), 450-466.
- Latorre, C., Betancourt, J., Rylander, K. and Quade, J., 2002. Vegetation invasions into Absolute Desert: A 45,000-yr rodent midden record from the Calama-Salar de Atacama Basins, northern Chile (22°-24°S). *Geological Society of America Bulletin* 114(3), 349-366.

- Latorre, C., Betancourt, J., Rylander, K., Quade, J. and Matthei, O., 2003. A vegetation history from the arid prepuna of northern Chile (22–23°S) over the last 13 500 years. *Palaeogeography, Palaeoclimatology, Palaeoecology* 194(1–3), 223-246.
- Lavallée, D., 2006. Secuencias y consecuencias de algunos procesos de neolitización en los Andes Centrales. *Estudios Atacameños* 32, 35-41.
- Le Paige, G., 1958. Antiguas culturas atacameñas en la cordillera Chilena. *Anales de la Universidad Católica de Valparaíso* 4-5, 15-91.
- Le Paige, G., 1963. Continuidad o discontinuidad de la Cultura Atacameña. *Anales de la Universidad del Norte* 2, 7-25.
- Le Paige, G., 1973. Tres cementerios indígenas en San Pedro de Atacama y Toconao. *Actas del VI Congreso Nacional de Arqueología Chilena*. 163-187.
- Le Paige, G., 1974. El yacimiento de Tchaputchayna. *Estudios Atacameños* 2, 59-74.
- Le Paige, G., 1975. Se puede hablar de transhumancia en la zona Atacameña? *Estudios Atacameños* 3, 11-16.
- Leach, E., 1964. Anthropological aspects of language: animal categories and verbal abuse. In: E. Lennenberg (ed.), *New directions in the study of language*. Cambridge: MIT Press, 23-64.
- Lederberger-Crespo, P. (ed.) 2000. *El Formativo sudamericano. Una reevaluación*, Quito: Ediciones Abya-Yala.
- Lee-Thorp, J., Sealy, J. and Van Der Merwe, N., 1989. Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. *Journal of Archaeological Science* 16(6), 585-599.
- Lema, V.S., 2009. Domesticación vegetal y grados de dependencia ser humano-planta en el desarrollo cultural prehispánico del Noroeste Argentino. Unpublished PhD thesis, Universidad Nacional de La Plata.

- Lema, V.S., Della Negra, C. and Bernal, V., 2012. Explotación de recursos vegetales silvestres y domesticados en Neuquén: implicancias del hallazgo de restos de maíz y algarrobo en artefactos de molienda del Holoceno Tardío. *Magallania* 40(1), 229-247.
- Levi-Strauss, C., 1966. *The savage mind*. Chicago: The University of Chicago Press.
- Lia, V.V., Confalonieri, V.A., Ratto, N., Cámara Hernández, J.A., Miente Alzogaray, A.M., Poggio, L. and Brown, T.A., 2007. Microsatellite Typing of Ancient Maize: Insights into the History of Agriculture in Southern South America. *Proceedings of the Royal Society of Biological Sciences* 274(1609), 545-554.
- Liu, L., Ge, W., Bestel, S., Jones, D., Shi, J., Song, Y. and Chen, X., 2011. Plant exploitation of the last foragers at Shizitan in the Middle Yellow River Valley China: evidence from grinding stones. *Journal of Archaeological Science* 38(12), 3524-3532.
- Llagostera, A., 1979. 9,700 Years of Maritime Subsistence on the Pacific: An Analysis by Means of Bioindicators in the North of Chile. *American Antiquity* 44(2), 309-324.
- Llagostera, A., 1988. Informe sobre investigaciones arqueológicas en Calar. *Boletín de la Sociedad Chilena de Arqueología* 8(1).
- Llagostera, A., 1996. San Pedro de Atacama: Nodo de complementariedad reticular. *Estudios y Debates Regionales Andinos* 91, 17-42.
- Llagostera, A., Barón, A. and Bravo, L., 1984. Investigaciones arqueológicas en Tular 1. *Estudios Atacameños* 7, 105-115.
- Llagostera, A. and Costa, M., 1999. Patrones de asentamiento en la época Agroalfarera de San Pedro de Atacama (norte de Chile). *Estudios Atacameños* 17, 175-206.
- Llano, C. and Ugan, A., 2009. Economic return rates of wild plants in southern Mendoza: nutritional values, handling cost and archaeological interpretations. *V Congreso Internacional de Etnobotánica*. Bariloche.

- Llano, C., Ugan, A., Guerci, A. and Otaola, C., 2012. Arqueología experimental y valoración nutricional del fruto de algarrobo (*Prosopis flexuosa*): inferencias sobre la presencia de macrorrestos en sitios arqueológicos. *Intersecciones en Antropología* 13, 513-524.
- Logan, A., 2006. The application of phytolith and starch grain analysis to understanding Formative period subsistence, ritual, and trade on the Taraco Peninsula, Highland Bolivia. Unpublished MA thesis, University of Missouri.
- López, P., 2010. Isótopos estables en restos de camélidos de Quebrada Tulán (II Región-Chile): uso del espacio durante el Formativo Temprano (ca. 3.100-2.400 AP). Unpublished MSc thesis, Universidad Católica del Norte-Universidad de Tarapacá.
- Loy, T.H., 1987. Recent advances in blood residue analysis In: W.R. Ambrose & J.M.J. Mummery (eds.), *Archaeometry: further Australasian studies*. Canberra: Australian National University, 57-65.
- Loy, T.H., 1994. Methods in the analysis of starch residues on prehistoric stone tools. In: J. Hather (ed.), *Tropical archaeobotany, applications and new developments*. London: Routledge, 86-114.
- Loy, T.H., Spriggs, M. and Wickler, S., 1992. Direct evidence for human use of plants 28,000 years ago: starch residues on stone artefacts from the northern Solomon Islands. *Antiquity* 66(253), 898-912.
- Lu, H. and Liu, K., 2003. Phytoliths of common grasses in the coastal environments of southeastern USA. *Estuarine, Coastal and Shelf Science* 58(3), 587-600.
- Lu, T., 2003. The survival of starch in a subtropical environment. In: D.M. Hart & L.A. Wallis (eds.), *Phytolith and starch research in the Australasian-Pacific-Asian Regions: the state of the art*. Canberra: Pandanus Books, 119-126.
- Lumbreras, L.G., 1974. *La arqueología como ciencia social*. Lima: Ediciones Hístar.
- Lumbreras, L.G., 2006. Un Formativo sin cerámica y cerámica preformativa. *Estudios Atacameños* 32, 11-34.

- Lynch, T., 1967. The nature of the Central Andean Preceramic. *Occasional Papers of the Idaho State University Museum* 21.
- Macneish, R. and Eubanks, M., 2000. Comparative Analysis of the Río Balsas and Tehuacán Models for the Origin of Maize. *Latin American Antiquity* 11(1), 3-20.
- Macneish, R., Patterson, T.C. and Browman, D.L., 1975. The Central Peruvian prehistoric interaction sphere. *Papers of the Robert S. Peabody Foundation for Archaeology* 7, 1-97.
- Madella, M. and Lancelotti, C., 2011. Taphonomy and phytoliths: A user manual. *Quaternary International* 275, 76-83.
- Madrazo, G., 1981. Comercio interétnico y trueque recíproco equilibrado intraétnico. Desarrollo Económico. *Revista de Ciencias Sociales* 21(82), 213-230.
- Malagamba, P. and Kalazich, J., 2011. Genética de Ila Patata. In: L. Frusciante, G. Roversi & I. Ponti (eds.), *La Patata*. Bologna: Script Bologna, 622-631.
- Maldonado, A., Betancourt, J., Latorre, C. and Villagran, C., 2005. Pollen analyses from a 50 000-yr rodent midden series in the southern Atacama Desert (25 30' S). *Journal of Quaternary Science* 20(5), 493-507.
- Mangelsdorf, P.C. and Pollard, G.C., 1975. *Archaeological maize from Northern Chile*. Cambridge: Harvard University.
- Marcos, J.J., 2003. A reassessment of the Ecuadorian Formative. In J.S. Raymond & R. Burger (eds.) *Archaeology of Formative Ecuador*. Washington DC: Dumbarton Oaks.
- Marquet, P., Bozinovic, F., Bradshaw, A., Cornelius, C., González, H., Gutiérrez, J., Hajek, E., Lagos, J., López-Cortés, F., Núñez, L., Rosello, E., Santoro, C., Samaniego, H., Standen, V., Torres-Mura, J. and Jaksic, F., 1998. Los ecosistemas del Desierto de Atacama y area Andina adyacente en el norte de Chile. *Revista Chilena de Historia Natural* 71, 593-617.

- Martínez, E.A., Veas, E., Jorquera, C., San, M., R. and Jara, P., 2009. Re-Introduction of Quinoa into Arid Chile: Cultivation of Two Lowland Races under Extremely Low Irrigation. *Journal of Agronomy and Crop Science* 195(1), 1-10.
- Martínez, J.L., 1998. *Pueblos del chañar y el algarrobo: los Atacamas en el siglo XVII*. Santiago: DIBAM.
- Matsuoka, Y., Vigouroux, Y., Goodman, M., Sanchez, J., Buckler, E. and Doebley, J., 2002. A single domestication for maize shown by multilocus microsatellite genotyping. *Proceedings of the National Academy of Sciences* 99(9), 6080-6084.
- Mauldin, R., 1993. The Relationship between Ground Stone and Agricultural Intensification in Western New Mexico. *Kiva* 58(3), 317-330.
- Mcandrews, T., 1998. Early Village-Based Society and Long-Term Cultural Evolution in the South-Central Andean Altiplano. Unpublished PhD thesis, University of Pittsburgh.
- Mcclure, S., Jochim, M.A. and Barton, M.C., 2006. Human behavioral ecology, domestic animals, and land use during the transition to agriculture in Valencia, Eastern Spain. In: D. Kennett & B. Winterhalder (eds.), *Human behavioral ecology and the transition to agriculture*. Berkeley: University of California Press, 197-216.
- Mcconn, M.M. and Nakata, P.A., 2004. Oxalate Reduces Calcium Availability in the Pads of the Prickly Pear Cactus through Formation of Calcium Oxalate Crystals. *Journal of Agricultural and Food Chemistry* 52(5), 1371-1374.
- Mccorkle, C., 1987. Punas, pastures, and fields; grazing strategies and the agropastoral dialectic in an indigenous Andean community. In: D. Browman (ed.), *Arid land use strategies and risk management in the Andes*. Boulder: Westview Press, 57-79.
- Mcrostitie, V., 2004. *Evidencias Arqueobotánicas en Tulan 122, Salar de Atacama, Chile*. Proyecto Fondecyt 1020316. Santiago. Unpublished report.

- Mcrostitie, V., 2007. La transición Arcaico-Formativa en la quebrada de Tulán, sur del Salar de Atacama, Chile. Evidencias arqueobotánicas. Unpublished undergraduate thesis, Universidad de Chile.
- Mcrostitie, V., 2008. *Informe arqueobotánico Sitio Tu-85*. Proyecto Fondecyt 1070040. Unpublished report.
- Meggers, B., 1973. Some problems of cultural adaptation in Amazonia, with emphasis on the pre-European period. In: B. Meggers, E.D. Ayensu & W.D. Duckworth (eds.), *Tropical forest ecosystems in Africa and South America: a comparative review*. Washington DC: Smithsonian Institution Press, 311-320.
- Meggers, B., 1985. El significado de la difusión como factor de evolución. *Chungara* 14, 81-90.
- Mena, F., 1984. Patrones de movilidad en el Arcaico Tardío: II Región. *Estudios Atacameños* 7, 25-35.
- Mengoni, G.L., 2008. Camelids in ancient Andean societies: A review of the zooarchaeological evidence. *Quaternary International* 185(1), 59-68.
- Mengoni, G.L., 2009. La domesticación de camélidos en el NOA: el aporte de los análisis de isótopos estables. In: P. López, I. Cartajena, C. García & F. Mena (eds.), *Zooarqueología y Tafonomía en el Confín del Mundo*. Santiago: Ediciones Universidad Internacional SEK-Chile, 181-198.
- Mengoni, G.L. and Yacobaccio, H., 2006. The domestication of South American camelids. A view from the South-Central Andes. In: M. Zeder, D. Bradley, E. Emshwiller & B.D. Smith (eds.), *Documenting domestication: new genetic and archaeological paradigms*. Berkeley: University of California Press, 228-244.
- Messerli, B., Grosjean, M., Bonani, G., Burgi, A., Geyh, M.A., Graf, K., Ramseyer, K., Romero, H., Schotterer, U., Schreier, H. and Vuille, M., 1993. Climate change and natural resource dynamics of the Atacama Altiplano during the last 18,000 years; a preliminary synthesis. *Mountain Research and Development* 13(2), 117-127.

- Messner, T.C., 2008. Woodland period people and plant interactions: new insights from starch grain analysis. Unpublished PhD thesis, Temple University.
- Milton, K., 2000. Hunter-gatherer diets- a different perspective. *American Journal of Clinical Nutrition* 71(3), 665-667.
- Minnis, P., 1985. *Social adaptation to food stress: a prehistoric southwestern example*. Chicago: University of Chicago Press.
- Minnis, P., 1991. Famine foods of the Northern American Desert borderlands in historical context. *Journal of Ethnobiology* 11(2), 231-257.
- Minnis, P., 1992. Earliest plant cultivation in the desert borderlands of North America. In: C.W. Cowan & P.J. Watson (eds.), *The origins of agriculture: an international perspective*. Washington: Smithsonian Press, 121-141.
- Mondini, M. and Elkin, D., 2006. Cazadores-recolectores de la cuenca de Antofagasta de la Sierra (Puna Meridional Argentina): una perspectiva zooarqueológica y tafonómica. Cazadores y Recolectores del Cono Sur. *Revista de Arqueología* 1, 69-81.
- Monsalve, S., 1985. A pollen core from the Hacienda Lusitania. *ProCalima* 4, 40-44.
- Montaldo, A. and Sanz, C., 1962. Las especies de papas silvestres y cultivadas de Chile. *Agricultura Técnica* 22(1-2), 66-152.
- Montaldo, P., 1974. Regiones ecológicas del cultivo de la papa (*Solanum tuberosum*) en Chile. *Agro sur* 2(1), 25-27.
- Moraga, M., Venegas, J., Westfall, C. and González, C., 2006. Análisis prospectivo de ADN mitocondrial y ADN nuclear en muestras humanas del sitio Formativo Cementerio Regimiento Chorrillos de Calama.
- Moseley, M., 1975. *The maritime foundations of Andean civilization*. Menlo Park: Cummings Publishing Company.

- Moseley, M., 1992. Maritime foundations and multilinear evolution: Retrospect and prospect. *Andean Past* 3, 5-42.
- Mostny, G., 1954. *Peine, un pueblo atacameño*. Santiago: Instituto de Geografía, Facultad de Filosofía, Universidad de Chile.
- Mulholland, S.C., 1989. Phytolith shape frequencies in North Dakota grasses: a comparison to general patterns. *Journal of Archaeological Science* 16(5), 489-511.
- Mulholland, S.C., 1993. A test of phytolith analysis at Big Hidatsa, North Dakota. In: D. Pearsall & D. Piperno (eds.), *Current research in phytolith analysis: applications in archaeology and paleoecology*. Philadelphia: MASCA, 131-145.
- Munizaga, C., Gunckel, H. and Baraona, R., 1958. Notas etnobotánicas del pueblo atacameño de Socaire. *Centro de Estudios Antropológicos* 5, 9-44.
- Muñoz, C., 1973. *Plantas en extinción*. Santiago: Editorial Universitaria.
- Muñoz, I., 1983. La fase Alto Ramírez en los valles del extremo norte de Chile. *Documentos de Trabajo* 3, 3-42.
- Muñoz, I., 1989. El Período Formativo en el Norte Grande (100 a.C. a 500 d. C.). In: J. Hidalgo, V. Schiappacasse, H. Niemeyer, C. Aldunate & I. Solimano (eds.), *Culturas de Chile: prehistoria. Desde sus orígenes hasta los albores de la conquista*. Santiago: Andrés Bello, 107-128.
- Muñoz, I., 2004. *Estrategias de organización prehispánicas en Azapa: el impacto de la agricultura en un valle del desierto costero del Pacífico*. Arica: Ediciones Universidad de Tarapaca.
- Muñoz, I., Rocha, R. and Chacon, S., 1991. Camarones 15. Asentamiento de pescadores correspondiente al periodo Arcaico y Formativo en el extremo Norte de Chile. *Actas del XI Congreso de Arqueología Chilena*. 1-24.
- Murdock, G.P., 1967. Ethnographic Atlas: A Summary. *Ethnology* 6(2), 109-236.

- Murra, J., 1972. El "control vertical" de un máximo de pisos ecológicos en la economía de las sociedades andinas. In: J. Murra (ed.), *Visita a la provincia de León de Huánuco en 1562, Iñigo Ortiz de Zúñiga*. Huánuco: Universidad Emilio Valdizán, 429-472.
- Murra, J., 1975. *Formaciones económicas y políticas en el mundo Andino*. Lima: Instituto de Estudios Peruanos.
- Murra, J., 1985a. El Archipiélago Vertical "revisited". In: S. Masuda, I. Shimada & C. Morris (eds.), *Andean ecology and civilization: an interdisciplinary perspective on Andean ecological complementarity*. Tokyo: University of Tokyo Press, 3-13.
- Murra, J., 1985b. The limits and limitations of the "Vertical Archipelago". In: S. Masuda, I. Shimada & C. Morris (eds.), *Andean ecology and civilization: an interdisciplinary perspective on Andean ecological complementarity*. Tokyo: University of Tokyo Press, 15-20.
- Muscio, H., 1999. Colonización humana del NOA y variación en el consumo de los recursos: la ecología de los cazadores recolectores de la Puna durante la transición Pleistoceno-Holoceno. *Naya*. 1-49.
- Muscio, H., 2001. *Una revisión crítica del Arcaico surandino*. Buenos Aires: OPFYL, Universidad de Buenos Aires.
- Neilson, J., Quade, J., Ortiz, M., Nelson, W., Legatzki, A., Tian, F., Lacombe, M., Betancourt, J., Wing, R., Soderlund, C. and Maier, R., 2012. Life at the hyperarid margin: novel bacterial diversity in arid soils of the Atacama Desert, Chile. *Extremophiles* 16, 553-566.
- Nester, P.L., Gayó, E.M., Latorre, C., Jordan, T.E. and Blanco, N., 2007. Perennial stream discharge in the hyperarid Atacama Desert of northern Chile during the latest Pleistocene. *Proceedings of the National Academy of Sciences* 104(50), 19724-19729.
- Neves, W. and Costa, M., 1998. Adult stature and standard of living in the prehistoric Atacama Desert. *Current Anthropology* 39(2), 278-281.

- Nichols, D.L., 1987. Risk and Agricultural Intensification during the Formative Period in the Northern Basin of Mexico. *American Anthropologist* 89(3), 596-616.
- Noli, E., 1999. La recolección en la economía de subsistencia de las poblaciones indígenas: una aproximación a través de las fuentes coloniales (piedemonte y llanura tucumano-santiagueña, Gobernación del Tucumán). In: C. Aschero, M.A. Korstanje & P. Vuoto (eds.), *En los tres reinos: prácticas de recolección en el Cono Sur de América*. Tucumán: Instituto de Arqueología y Museo, Facultad de Ciencias Naturales e Instituto Miguel Lillo, Universidad Nacional de Tucumán.
- Nopal Cactus, N.D. *Welcome to Nopal Cactus* [online]. <http://www.cactusnopal.net>. [Accessed 3 May 2013].
- Nordstrom, C., 1990. *Evidence for the Domestication of Chenopodium in the Andes*. Report to the National Science Foundation. Archaeobotany Laboratory Report 19 on file, Paleoethobotany Laboratory. Berkeley.
- Núñez, L., 1962. Tallas prehispánicas en madera. Contribución a la arqueología del Norte de Chile. Unpublished undergraduate thesis, Universidad de Chile.
- Núñez, L., 1969. Sobre los complejos culturales Chinchorro y Faldas del Morro del Norte de Chile. *Revista Rehue* 2, 11-42.
- Núñez, L., 1971. Secuencia y cambio en los asentamientos humanos de la desembocadura del río Loa en el norte de Chile. *Boletín de la Universidad de Chile* 112, 3-25.
- Núñez, L., 1974. *Agricultura prehistórica en los Andes Meridionales*. Santiago: Editorial Orbe.
- Núñez, L., 1980. Hipótesis de movilidad trashumántica en la Puna de Atacama: Quebrada de Tulan (nota preliminar). *Actas del V Congreso Nacional de Arqueología Argentina*. San Juan, 19-46.
- Núñez, L., 1981a. Asentamiento de cazadores recolectores tardíos en la Puna de Atacama: Hacia el sedentarismo *Chungara* 8, 137-168.

- Núñez, L., 1981b. Emergencia de sedentarismo en el desierto Chileno. *Revista Creces* 11, 33-38.
- Núñez, L., 1982. Temprana emergencia de sedentarismo en el desierto Chileno: proyecto Caserones. *Chungara* 9, 80-122.
- Núñez, L., 1984. El asentamiento Pircas: Nuevas evidencias de tempranas ocupaciones agrarias en el norte de Chile. *Estudios Atacameños* 11, 152-175.
- Núñez, L., 1986-1987. *Análisis multidisciplinario de domesticación y crianza inicial de camélidos en Los Andes del Norte de Chile*. Unpublished report.
- Núñez, L., 1989. Hacia la producción de alimentos y la vida sedentaria. In: J. Hidalgo, V. Schiappacasse, H. Niemeyer, C. Aldunate & I. Solimano (eds.), *Culturas de Chile: prehistoria. Desde sus orígenes hasta los albores de la conquista*. Santiago: Andrés Bello, 81-105.
- Núñez, L., 1992. Ocupación arcaica en la Puna de Atacama: secuencia, movilidad y cambio. In: B. Meggers (ed.), *Prehistoria sudamericana: nuevas perspectivas*. Washington: Taraxacum.
- Núñez, L., 1993. Los recursos agropecuarios del Norte de Chile al tiempo de la invasión Europea. *Actas del II Simposio Internacional de Estudios Altiplánicos*. Arica.
- Núñez, L., 1994. Emergencia de complejidad y arquitectura jerarquizada en la Puna de Atacama: las evidencias del sitio Tulan-54. In: M.E. Albeck (ed.), *De costa a selva*. Tilcara: Instituto Interdisciplinario Tilcara, 85-115.
- Núñez, L., 1995. Evolución de la ocupación y organización del espacio atacameño. Aspectos dinámicos. In: P. Pourrut & L. Núñez (eds.), *Agua, ocupación del espacio y economía campesina en la región atacameña*. Antofagasta: Universidad Católica del Norte - ORSTOM, 18-60.
- Núñez, L., 2005. La naturaleza de la expansión aldeana durante el Formativo Tardío en la Cuenca de Atacama. *Chungara* 37(2), 165-193.

- Núñez, L., 2007. *Vida y cultura en el oasis de San Pedro de Atacama*. Santiago: Editorial Universitaria.
- Núñez, L., Cartajena, I., Carrasco, C. and De Souza, P., 2002-2005. *Informes Proyecto Fondecyt 1020316: Transición del Arcaico Tardío al Formativo Temprano en la cuenca de Atacama: Emergencia de la Complejidad socio Cultural en la Subárea Circumpuneña*. Unpublished reports.
- Núñez, L., Cartajena, I., Carrasco, C. and De Souza, P., 2005. El Templete Tulán de la Puna de Atacama: Emergencia de Complejidad Ritual Durante el Formativo Temprano (Norte de Chile). *Latin American Antiquity* 17(4), 445-473.
- Núñez, L., Cartajena, I., Carrasco, C., De Souza, P. and Grosjean, M., 2006. Emergencia de comunidades pastoralistas formativas en el sureste de la Puna de Atacama. *Estudios Atacameños* 32, 93-117.
- Núñez, L. and Dillehay, T., 1979. *Movilidad giratoria, armonía y desarrollo en los Andes Meridionales; patrones de tráfico e interacción económica*. Antofagasta: Dirección General de Investigaciones Tecnológicas, Universidad del Norte.
- Núñez, L. and Grosjean, M., 1994. Cambios ambientales pleistoceno-holocénicos: Ocupación humana y uso de recursos en la Puna de Atacama (Norte de Chile). *Estudios Atacameños* 11, 11-24.
- Núñez, L., Grosjean, M. and Cartajena, I., 1999. Un ecorefugio oportunístico en la puna de Atacama durante eventos áridos del Holoceno Medio. *Estudios Atacameños* 17, 125-174.
- Núñez, L., Grosjean, M. and Cartajena, I., 2002. Human Occupations and Climate Change in the Puna de Atacama, Chile. *Science* 298(5594), 821-824.
- Núñez, L., Grosjean, M., Cartajena, I. and Pino, M., 1995-96. Proyecto Puripica: reconstrucción multidisciplinaria de eventos Holocénicos culturales y ambientales. *Hombre y Desierto* 9, 273-290.

- Núñez, L., Grosjean, M., Messerli, B. and Schreliier, H., 1995. Cambios ambientales holocénicos en la puna de Atacama y sus implicancias paleoclimáticas. *Estudios Atacameños* 12, 31-40.
- Núñez, L., Mcrostitie, V. and Cartajena, I., 2009. Consideraciones sobre la recolección vegetal y la horticultura durante el Formativo temprano en el Sureste de la Cuenca de Atacama. *Darwiniana* 47(1), 56-75.
- Núñez, L. and Moragas, C., 1977. Una ocupación con cerámica temprana en la secuencia del distrito de Cádiz (costa desértica del norte de Chile). *Estudios Atacameños* 5, 21-49.
- Núñez, L. and Santoro, C., 1988. Cazadores de la puna seca y salada del área centro-sur Andina (Norte de Chile). *Estudios Atacameños* 9, 11-60.
- Núñez, L. and Santoro, C., 2011. El tránsito Arcaico-Formativo en la Circumpuna y Valles Occidentales del Centro Sur Andino: Hacia los cambios "Neolíticos". *Chungara* 43(1), 487-530.
- Núñez, M.K., 1998. Peine: Saber andino, manejo de recursos y transformaciones. *Estudios Atacameños* 16, 283-292.
- Ochoa, C. and Ugent, D., 2001. Maca (*Lepidium meyenii* Walp.; Brassicaceae): A Nutritious Root Crop of the Central Andes. *Economic Botany* 55(3), 344-345.
- Oliszewski, N., 2004. Utilización de recursos vegetales en Campo del Pucara (Andalgala, Catamarca) durante el Periodo Formativo (200-500 D.C.). Análisis de macrorrestos. Unpublished PhD thesis, Universidad Nacional del Tucumán.
- Olivera, D., 1998. Cazadores y pastores tempranos de la Puna Argentina. In S. Ahlgren, A. Muñoz, S. Sjödin & P. Stenborg (eds.) *Past and Present in Andean Prehistory and Early History*. Göteborg: Etnografiska Museet, 153 -180.

- Olivera, D., 2001. Sociedades agropastoriles tempranas: el Formativo Inferior del Noroeste Argentino. In: E. Berberian & A. Nielsen (eds.), *Historia argentina prehispánica*. Córdoba: Brujas, 83-125.
- Olivera, D., Tchilinguirian, P. and Grana, L., 2004. Paleoambiente y arqueología en la Puna Meridional Argentina: archivos ambientales, escalas de análisis y registro arqueológico. *Relaciones de la Sociedad Argentina de Antropología* 29, 229-247.
- Olivera, D., Tchilingurian, P. and Aguirre, M., 2006. Cultural and Environmental Evolution in the Meridional Sector of the Puna of Atacama during the Holocene. *Change in the Andes: Origins of Social Complexity, Pastoralism and Agriculture*. Liège, Belgium: BAR International Series.
- Olivera, D. and Yacobaccio, H., 1999. Estudios de paleodieta en poblaciones humanas de los Andes del Sur a través de isótopos estables. *V Congreso Nacional de Paleopatología, Alcalá La Real, Jaén*.
- Ollendorf, A.L., 1992. Towards a classification scheme of sedge (Cyperaceae) phytoliths. In: G. Rapp & S.C. Mulholland (eds.), *Phytolith systematics: emerging issues*. New York: Plenum Press, 91-111.
- Orellana, M., 1984. Influencias altiplánicas en San Pedro de Atacama. *Estudios Atacameños* 7, 149-157.
- Orellana, M., 1988-1989. Los tipos alfareros tempranos de Calar y su contexto aldeano. *Paleoetnológica* 5, 73-86.
- Ormazábal, C.S., 1991. Silvopastoral systems in arid and semiarid zones of northern Chile. *Agroforestry Systems* 14(3), 207-217.
- Osterrieth, M., Madella, M., Zurro, D. and Alvarez, M., Fernanda, 2009. Taphonomical aspects of silica phytoliths in the loess sediments of the Argentinean Pampas. *Quaternary International* 193(1-2), 70-79.

- Pagán-Jiménez, J.R., 2007. *De antiguos pueblos y culturas botánicas en el Puerto Rico indígena: el archipiélago borincano y la llegada de los primeros pobladores agroceramistas*. Oxford: Archaeopress.
- Palacios, R. and Brizuela, M., 2005. Prosopis: historia y elementos para su domesticación. *Agrociencia* 9(1), 41-51.
- Panarello, O., Tessone, A. and Zangrando, A., 2006-2009. Isótopos estables en arqueología: principios teóricos, aspectos metodológicos y aplicaciones en Argentina. *Xama* 19 - 23, 115-133.
- Pardo, O., 2007. El amañoco, *Ombrophytum subterraneum* (Aspl.) B. Hansen, como alimento en la Región de Arica-Parinacota (XV), Chile *Chloris Chilensis*. 16.
- Pardo, O. and Pizarro, J., 2005. *Especies botánicas consumidas por los chilenos prehispánicos*. Santiago: Mare Nostrum.
- Parker Pearson, M., 2003. Food, identity and culture: an introduction and overview. In: M. Parker Pearson (ed.), *Food, culture and identity in the Neolithic and early Bronze Age*. Oxford: Archaeopress, 1-30.
- Parodi, L.R., 1966. *La agricultura aborígen Argentina*. Buenos Aires: Editorial Universitaria de Buenos Aires.
- Pasiecznik, N., Felker, P., Harris, P., Harsh, L., Cruz, G., Tewari, J., Cadoret, K. and Maldonado, L., 2001. *The Prosopis juliflora complex: a monograph*. Coventry, UK: HDRA.
- Pate, F.D., 1994. Bone chemistry and paleodiet. *Journal of Archaeological Method and Theory* 1(2), 161-209.
- Pearsall, D., 1978. Phytolith analysis of archeological soils: Evidence for maize cultivation in Formative Ecuador. *Science* 199(4325), 177-178.

- Pearsall, D., 1989. Adaptation of prehistoric hunter-gatherers to the high Andes: The changing role of plant resources. In: D.R. Harris & G.C. Hillman (eds.), *Foraging and farming: the evolution of plant exploitation*. London: Unwin-Hyman, 318-332.
- Pearsall, D., 1992. The origin of plant cultivation in South America. In: C.W. Cowan & P.J. Watson (eds.), *The origins of agriculture: an international perspective*. Washington: Smithsonian Institution Press, 173-205.
- Pearsall, D., 1994. Issues in the analysis and interpretation of archaeological maize in South America. In: C. Hastorf & S. Johannessen (eds.), *Corn and culture in the prehistoric New World*. Boulder: Westview Press, 245-272.
- Pearsall, D., 1995. Domestication and agriculture in the New World tropics. In: D.T. Price & A.B. Gebauer (eds.), *Last hunters, first farmers: new perspectives on the prehistoric transition to agriculture*. Santa Fe: School of American Research Press, 157-192.
- Pearsall, D., 1999. The impact of maize on subsistence systems in South America: an example from the Jama River Valley, coastal Ecuador. In: C. Gosden & J. Hather (eds.), *The prehistory of food: appetites for change*. London; New York: Routledge, 408-426.
- Pearsall, D., 2000. *Paleoethnobotany: a handbook of procedures*. London: Academic Press.
- Pearsall, D., 2003. Plant food resources of the Ecuadorian Formative: an overview and comparison to the Central Andes. In: J. Raymond & R. Burger (eds.), *Archaeology of Formative Ecuador*. Washington: Dumbarton Oaks, 213-257.
- Pearsall, D., 2007. The impact of maize on subsistence systems in South America: an example from the Jama river valley, coastal Ecuador (1999). In: T. Denham & P. White (eds.), *The emergence of agriculture: a global view*. New York: Routledge, 83-103.
- Pearsall, D., 2008. Plant domestication and the shift to agriculture in the Andes. In: H. Silverman & W. Isbell (eds.), *Handbook of South American Archaeology*. New York: Springer, 105-120.

- Pearsall, D., 2009. Investigating the transition to agriculture. *Current Anthropology* 50(5), 609-613.
- Pearsall, D., Chandler-Ezell, K. and Chandler-Ezell, A., 2003. Identifying maize in neotropical sediments and soils using cob phytoliths. *Journal of Archaeological Science* 30(5), 611-627.
- Pearsall, D., Chandler-Ezell, K. and Zeidler, J.A., 2004. Maize in ancient Ecuador: results of residue analysis of stone tools from the Real Alto site. *Journal of Archaeological Science* 31(4), 423-442.
- Pearsall, D. and Piperno, D., 1990. Antiquity of Maize Cultivation in Ecuador: Summary and Reevaluation of the Evidence. *American Antiquity* 55(2), 324-337.
- Pérez, S., 2010. Variabilidad en la producción de palas y/o azadas líticas de la Puna argentina. *Estudios Atacameños* 40, 5-22.
- Perry, L., 2004. Starch analyses reveal the relationship between tool type and function: an example from the Orinoco valley of Venezuela. *Journal of Archaeological Science* 31(8), 1069-1081.
- Perry, L., 2007. Starch remains, preservation biases, and plant histories. In: T. Denham, L. Vrydaghs & J. Iriarte (eds.), *Rethinking agriculture: archaeological and ethnographic perspectives*. Walnut Creek: Left Coast Press, 241-255.
- Perry, L., Dickau, R., Zarrillo, S., Holst, I., Pearsall, D., Piperno, D., Berman, M.J., Cooke, R., Rademaker, K., Ranere, A., Raymond, J., Sandweiss, D., Scaramelli, F., Tarble, K. and Zeidler, J., 2007. Starch Fossils and the Domestication and Dispersal of Chili Peppers (*Capsicum* sp. L.) in the Americas. *Science* 315(5814), 986-988.
- Perry, L., Sandweiss, D.H., Piperno, D., Rademaker, K., Malpass, M.A., Umlire, A. and De La Vera, P., 2006. Early maize agriculture and interzonal interaction in southern Peru. *Nature* 440(7080), 76-79.

- Philippi, R.A., 1860. *Viage al desierto de Atacama hecho de orden del gobierno de Chile en el verano 1853-54*. Santiago: Librería de Eduardo Antón.
- Pickersgill, B., 1971. Relationships Between Weedy and Cultivated Forms in Some Species of Chili Peppers (Genus *Capsicum*). *Evolution* 25(4), 683-691.
- Pickersgill, B., 1989. Cytological and genetical evidence on the domestication and diffusion of crops within the Americas. In: D.R. Harris & G.C. Hillman (eds.), *Foraging and farming: the evolution of plant exploitation*. London: Unwin Hyman, 426-439.
- Pickersgill, B., 2007. Domestication of Plants in the Americas: Insights from Mendelian and Molecular Genetics. *Annals of Botany* 100(5), 925-940.
- Pimentel, G., 2008. Evidencias formativas en una vía interregional entre San Pedro de Atacama y el Altiplano de Lípez. *Estudios Atacameños* 35, 7-33.
- Pintar, L., 2008. Estrategias de caza y recolección: una aproximación al tema de la división del trabajo en la Puna Salada durante el Holoceno Temprano y Medio. *Relaciones de la Sociedad Argentina de Antropología* 33, 133-154.
- Piperno, D., 1984. A Comparison and Differentiation of Phytoliths from Maize and Wild Grasses: Use of Morphological Criteria. *American Antiquity* 49(2), 361-383.
- Piperno, D., 1993. Phytolith and charcoal records from deep lake cores in the American Tropics. In: D. Pearsall & D. Piperno (eds.), *Current research in phytolith analysis: applications in archaeology and paleoecology*. Philadelphia: MASCA, 59-71.
- Piperno, D., 1995. Plant microfossils and their application in the New World tropics. In: P.W. Stahl (ed.), *Archaeology in the lowland American Tropics*. Cambridge: Cambridge University Press, 130-153.
- Piperno, D., 2006a. Identifying Manioc (*Manihot esculenta* Crantz) and Other Crops in Pre-Columbian Tropical America Through Starch Grain Analysis: A Case Study from Central Panama. In: M. Zeder, D. Bradley, E. Emschwiller & B. Smith (eds.),

Documenting Domestication: New Genetic and Archaeological Paradigms. Berkeley: University of California Press, 46-67.

Piperno, D., 2006b. The origins of plant cultivation and domestication in the neotropics: a behavioral ecological perspective. In: D. Kennet & B. Winterhalder (eds.), *Behavioral ecology and the transition to agriculture*. London: University of California Press, 137-166.

Piperno, D., 2006c. *Phytoliths: a comprehensive guide for archaeologists and paleoecologists*. Lanham: AltaMira Press.

Piperno, D., 2009. Identifying crop plants with phytoliths (and starch grains) in Central and South America: A review and an update of the evidence. *Quaternary International* 193(1-2), 146-159.

Piperno, D. and Dillehay, T., 2008. Starch grains on human teeth reveal early broad crop diet in northern Peru. *Proceedings of the National Academy of Sciences* 105(50), 19622-19627.

Piperno, D. and Flannery, K., 2001. The earliest archaeological maize (*Zea mays* L.) from highland Mexico: new accelerator mass spectrometry dates and their implications. *Proceedings of the National Academy of Sciences* 98(4), 2101-2103.

Piperno, D. and Fritz, G., 1994. On the Emergence of Agriculture in the New World. *Current Anthropology* 35(5), 637-643.

Piperno, D. and Holst, I., 1998. The presence of starch grains on prehistoric stone tools from the humid neotropics: Indications of early tuber use and agriculture in Panama. *Journal of Archaeological Science* 25(8), 765-776.

Piperno, D., Moreno, J.E., Iriarte, J., Holst, I., Lachniet, M., Jones, J.G., Ranere, A.J. and Castanzo, R., 2007. Late Pleistocene and Holocene environmental history of the Iguala Valley, Central Balsas Watershed of Mexico. *Proceedings of the National Academy of Sciences* 104(29), 11874-11881.

- Piperno, D. and Pearsall, D., 1998a. *The origins of agriculture in the Lowland Neotropics*. California: Academic Press.
- Piperno, D. and Pearsall, D., 1998b. The silica bodies of tropical American grasses: morphology, taxonomy, and implications for grass systematics and fossil phytolith identification. *Smithsonian Contributions to Botany* 85, 1-40.
- Piperno, D., Ranere, A., Holst, I. and Hansell, P., 2000. Starch grains reveal early root crop horticulture in the Panamanian tropical forest. *Nature* 407(6806), 894-897.
- Piperno, D., Ranere, A.J., Holst, I., Iriarte, J. and Dickau, R., 2009. Starch grain and phytolith evidence for early ninth millennium B.P. maize from the Central Balsas River Valley, Mexico. *Proceedings of the National Academy of Sciences* 106(13), 5019-5024.
- Piperno, D. and Stothert, K., 2003. Phytolith Evidence for Early Holocene Cucurbita Domestication in Southwest Ecuador. *Science* 299(5609), 1054-1057.
- Planella, M.T., 2005. Alero Las Morenas 1: evidencias de cultígenos entre cazadores recolectores de finales del período arcaico en Chile Central. *Chungara* 37(1), 59-74.
- Planella, M.T., 2011. Sitio El Plomo y nuevos registros de cultígenos iniciales en cazadores del Arcaico IV en Alto Maipo, Chile Central. *Chungara* 43(2), 189-202.
- Planella, M.T. and Tagle, B., 1995. La quinoa (*Chenopodium quinoa* Willd.) un aporte alimenticio ancestral hoy desconocido. *Gastroenterología Latinoamericana* 6(2), 70-83.
- Planella, M.T. and Tagle, B., 2004. Inicios de presencia de cultígenos en la zona Central de Chile, períodos Arcaico y Alfarero Temprano. *Chungara* 36(1), 387-399.
- Plowman, T., 1984. The origin, evolution and diffusion of coca (*Erythroxylum* spp.) in South and Central America. *Papers of the Peabody Museum of Archaeology and Ethnology* 76, 125-163.

- Pollard, G.C., 1970. The cultural ecology of ceramic stage settlement in the Atacama Desert. Unpublished PhD thesis, Columbia University.
- Pollard, G.C., 1971. Cultural change and adaptation in the central Atacama desert of Northern Chile. *Nawpa Pacha* 9, 41-68.
- Pollard, G.C. and Drew, I., 1975. Llama Herding and Settlement in Prehispanic Northern Chile: Application of an Analysis for Determining Domestication. *American Antiquity* 40(3), 296-305.
- Popper, V., 1987. Prehistoric cultivation in the Puna de Atacama, Chile. Unpublished B.A. thesis, Harvard University.
- Price, D.T. and Gebauer, A.B., 1995. New Perspectives on the transition to agriculture. In: D.T. Price & A.B. Gebauer (eds.), *Last hunters, first farmers: new perspectives on the prehistoric transition to agriculture*. Santa Fe: School of American Research Press, 3-20.
- Price, T., Burton, J. and Bentley, R., 2002. The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. *Archaeometry* 44(1), 117-136.
- Price, T., Knipper, C., Grupe, G. and Smrcka, V., 2004. Strontium isotopes and prehistoric human migration: the Bell Beaker period in central Europe. *European Journal of Archaeology* 7(1), 9-40.
- Prowse, T., Schwarcz, H.P., Saunders, S., Macchiarelli, R. and Bondioli, L., 2004. Isotopic paleodiet studies of skeletons from the Imperial Roman-age cemetery of Isola Sacra, Rome, Italy. *Journal of Archaeological Science* 31(3), 259-272.
- Quade, J., Rech, J., Latorre, C., Betancourt, J., Gleeson, E. and Kalin, M.T., 2007. Soils at the hyperarid margin: The isotopic composition of soil carbonate from the Atacama Desert, Northern Chile. *Geochimica et Cosmochimica Acta* 71(15), 3772-3795.
- Ravines, R., 1978. *Tecnología andina*. Lima: Instituto de Estudios Peruanos.

- Raymond, S. and Deboer, W., 2006. Maize on the Move. In: J. Staller, R. Tykot & J. Benz (eds.), *Histories of Maize. Multidisciplinary Approaches to the Prehistory, Linguistics, Biogeography, Domestication, and Evolution of Maize*. San Diego: Elsevier, 337-341.
- Rech, J., Quade, J. and Betancourt, J., 2002. Late Quaternary paleohydrology of the central Atacama Desert (lat 22-24°S), Chile. *Geological Society of America Bulletin* 114(3), 334-348.
- Reichert, E.T., 1913. *The differentiation and specificity of starches in relation to genera, species, etc: stereochemistry applied to protoplasmic processes and products, and as a strictly scientific basis for the classification of plants and animals*. Washington DC: Carnegie Institution of Washington.
- Reyes, O., 2005. *Informe Bioantropológico sitio Cementerio Regimiento Chorrillos*. Unpublished report.
- Riley, T., 2010. Assessing diet and seasonality in the Lower Pecos Canyonlands: an evaluation of coprolite specimens as records of individual dietary decisions. Texas A&M University.
- Rindos, D., 1984. *The origins of agriculture: an evolutionary perspective*. Orlando: Academic Press.
- Rivera, M., 2002. *Historias del desierto. Arqueología del Norte de Chile*. La Serena: Editorial del Norte.
- Rivera, M., 2005. *Arqueología del desierto de Atacama: la etapa formativa en el área de Ramaditas/Guatacondo*. Santiago: Universidad Bolivariana.
- Rivera, M., 2006. Prehistoric maize from northern Chile: an evaluation of the evidence. In: J. Staller, R. Tykot & B. Benz (eds.), *Histories of maize: multidisciplinary approaches to the prehistory, linguistics, biogeography, domestication and evolution of maize*. Amsterdam: Elsevier, 403-413.

- Rivera, M., Shea, D., Carevic, A. and Graffam, G., 1995-1996. En torno a los orígenes de las sociedades complejas andinas: Excavaciones en Ramaditas, una aldea formativa del desierto de Atacama, Chile. *Diálogo Andino* 14/15205-239.
- Rodríguez, M.F., 1999a. Arqueobotánica de Quebrada Seca 3 (Puna meridional argentina): especies vegetales utilizadas en la confección de artefactos durante el Arcaico. *Relaciones de la Sociedad Argentina de Antropología* 24, 159-185.
- Rodríguez, M.F., 1999b. Plant species (Families: Poaceae, Asteraceae, Fabaceae and Solanaceae) at an archaeological site of the Southern Argentine Puna *Journal of Ethnobiology* 19(2), 229-247.
- Rodríguez, M.F., 2000. Woody plant species used during the Archaic Period in the Southern Argentine Puna. Archaeobotany of Quebrada Seca 3. *Journal of Archaeological Science* 27(4), 341.
- Rodríguez, M.F., Agrasar, Z. and Aschero, C., 2006. El uso de las plantas en unidades domésticas del sitio arqueológico Punta de la Peña 4, Puna Meridional Argentina *Chungara* 38(2), 257-271.
- Rodríguez, M.F. and Aschero, C., 2007. Archaeological evidence of Zea mays (poaceae) in the Southern Argentinean Puna (Antofagasta de la Sierra, Catamarca). *Journal of Ethnobiology* 27(2), 256-271.
- Romero, A., Santoro, C., Valenzuela, D., Chacama, J., Rosello, E. and Piacenza, L., 2004. Túmulos, ideología y paisaje de la fase Alto Ramírez del valle de Azapa. *Chungara* 36(1), 261-272.
- Romero, H., Rivera, A. and Fernández, P., 1993. Climatología de la Puna de Atacama y su relación con los recursos hídricos. In: R. Charrier (ed.), *El altiplano, ciencia y conciencia de los Andes*. Santiago: Universidad de Chile, 87-93.
- Romo, M., 1998. Pastores del Sur Andino. Percepción y representación del ambiente. *Estudios Atacameños* 16, 209-231.

- Rosen, A., 1992. Preliminary identification of silica skeletons from Near Eastern archaeological sites: an anatomical approach. In: G. Rapp & S.C. Mulholland (eds.), *Phytolith systematics: advances in archaeological and museum science*. New York: Plenum Press, 129-147.
- Rosen, A., 2008. Phytolith Analysis. In D. Pearsall (ed.) *Encyclopedia of Archaeology*. San Diego and Oxford: Academic Press, 1818-1821.
- Rossen, J., 1991. Ecotones and low risk intensification. The Middle Preceramic habitation of Nanchoc, Northern Peru. Unpublished PhD thesis, University of Kentucky.
- Rossen, J., 2011. Las Pircas Phase (9800–7800 BP). In: T. Dillehay (ed.), *From foraging to farming in the Andes: new perspectives on food production and social organization*. Cambridge: Cambridge University Press, 99-117.
- Rostworowski De Diez Canseco, M., 1981. *Recursos naturales renovables y pesca, siglos XVI y XVI*. Lima: Instituto de Estudios Peruanos.
- Rothhammer, F., Santoro, C., Elie, P., Arriaza, B., Moraga, M. and Standen, V., 2009. Archeological and mtDNA evidence for Tropical Lowland migrations during the Late Archaic / Formative in northern Chile. *Revista Chilena de Historia Natural* 82, 543-552.
- Rovner, I., 2004. On transparent blindfolds comments on identifying maize in Neotropical sediments and soils using cob phytoliths. *Journal of Archaeological Science* 31(6), 815-819.
- Sanhueza, C., 1992. Tráfico caravanero y arriería colonial en el siglo XVI. *Estudios Atacameños* 10, 169-182.
- Sanhueza, C., 2008. Indios de los oasis, indios de la puna. Procesos migratorios y rearticulaciones identitarias en Atacama (Susques, Siglos XVIII-XIX). *Chungara* 40(2), 203-217.

- Santoro, C., 1980. Fase Azapa, transición del Arcaico al desarrollo agrario inicial en los valles bajos de Arica. *Chungara* 6, 46-56.
- Santoro, C. and Chacama, J., 1982. Secuencia cultural de las tierras altas del area Centro Sur Andina. *Chungara* 9, 22-45.
- Santoro, C., Núñez, L., Standen, V., González, H., Marquet, P. and Torres, A., 1998. Proyectos de irrigación y la fertilización del desierto. *Estudios Atacameños* 16, 321-336.
- Santoro, C., Ugalde, P., Latorre, C., Salas, C., Osorio, D., Jackson, D. and Gayó, E., 2011. Ocupación humana Pleistocénica en el Desierto de Atacama: Primeros resultados de la aplicación de un modelo predictivo de investigación interdisciplinaria. *Chungara* 43, 353-366.
- Sauer, C.O., 1952. *Agricultural origins and dispersals: the domestication of animals and foodstuffs*. Cambridge: MIT Press.
- Schiappacasse, V., Castro, V. and Niemeyer, H., 1989. Los Desarrollos Regionales en el Norte Grande (1000-1400d.C.). In: J. Hidalgo, V. Schiappacasse, H. Niemeyer, C. Aldunate & I. Solimano (eds.), *Culturas de Chile: prehistoria. Desde sus orígenes hasta los albores de la conquista*. Santiago: Andrés Bello.
- Schiffer, M.B., 1972. Archaeological Context and Systemic Context. *American Antiquity* 37(2), 156-165.
- Schiffer, M.B., 1983. Toward the Identification of Formation Processes. *American Antiquity* 48(4), 675-706.
- Schmeda-Hirschmann, G., Razmilic, I., Gutierrez, M.I. and Loyola, J.I., 1999. Proximate Composition and Biological Activity of Food Plants Gathered by Chilean Amerindians. *Economic Botany* 53(2), 177-187.
- Schoeninger, M. and Deniro, M., 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* 48(4), 625-639.

- Schwarcz, H.P., 2006. Stable carbon isotope analysis and human diet: a synthesis. In: J. Staller, R. Tykot & B.F. Benz (eds.), *Histories of maize: multidisciplinary approaches to the prehistory, linguistics, biogeography, domestication, and evolution of maize*. Amsterdam: Elsevier, 315-321.
- Sealy, J.C., Van Der Merwe, N.J., Thorp, J.a.L. and Lanham, J.L., 1987. Nitrogen isotopic ecology in southern Africa: Implications for environmental and dietary tracing. *Geochimica et Cosmochimica Acta* 51(10), 2707-2717.
- Seely, M., Al-Amoud, A., Chatty, D., Henschel, J., Kinahan, J., Kinahan, J., Klintenberg, P., León, A., Morrison, S., Roedern, C., Abraham, E., Felger, R., Laureano, P., Mouat, D., Portnov, B., Safriel, U., Schmidt, S., Sciortino, M., Warren, A. and Zohary, D., 2006. People and Deserts. In: E. Ezcurra (ed.), *Global desert overlook*. Nairobi: United Nations Environment Programme, 27-47.
- Sepúlveda, M., Romero, Á.L. and Briones, L., 2005. Tráfico de caravanas, arte rupestre y ritualidad en la quebrada de Suca (extremo norte de Chile). *Chungara* 37(2), 225-243.
- Serracino, G., 1985. Calarcoco 3: un yacimiento precerámico. *Chungara* 15, 31-44.
- Serracino, G. and Stehberg, R., 1975. Vida pastoril en la precordillera Andina. *Estudios Atacameños* 3, 73-88.
- Shady, R., 2006. Caral-Supe and the north-central area of Peru: the history of maize in the land where civilization came into being. In: J. Staller, R. Tykot & B.F. Benz (eds.), *Histories of maize: multidisciplinary approaches to the prehistory, linguistics, biogeography, domestication, and evolution of maize*. Amsterdam: Elsevier, 381-402.
- Shimada, M. and Shimada, I., 1985. Prehistoric Llama Breeding and Herding on the North Coast of Peru. *American Antiquity* 503-26.
- Sillar, B., 2000a. Dung by Preference: The choice of fuel as an example of how Andean pottery production is embedded within wider technical, social and economic practices. *Archaeometry* 42(1), 43-60.

- Sillar, B., 2000b. *Shaping culture: making pots and constructing households. An ethnoarchaeological study of pottery production, trade and use in the Andes*. Oxford: BAR.
- Silva, M., Martínez, M., Coirini, R., Brunetti, M., Balzarini, M. and Karlin, U., 2000. Valoración nutritiva del fruto del algarrobo blanco (*Prosopis chilensis*) bajo distintos tipos de almacenamiento. *Multequina* 9, 65-74.
- Sinclair, C., 1985. Dos fechas radiocarbónicas del alero Chulqui, río Toconce. Noticia y comentario. *Chungara* 14, 71-79.
- Sinclair, C., 2004. Prehistoria del período Formativo en la cuenca alta del río Salado (Región del Loa Superior). *Chungara* 36(2), 619-639.
- Sinclair, C., Uribe, M., Ayala, P. and González, J., 1998. La alfarería del Período Formativo en la Región del Loa Superior: sistematización y tipología. In S.C.D. Arqueología (ed.) *Actas del XIV Congreso Nacional de Arqueología Chilena*. Copiapó, 285-314.
- Smith, B., 1998a. Between Foraging and Farming. *Science* 279(5357), 1651-1652.
- Smith, B., 1998b. *The emergence of agriculture*. New York: Scientific American Library.
- Smith, B., 2001a. Documenting plant domestication: The consilience of biological and archaeological approaches. *Proceedings of the National Academy of Sciences* 98(4), 1324-1326.
- Smith, B., 2001b. Low-level food production. *Journal of Archaeological Research* 9(1), 1-43.
- Smith, B., 2006. Documenting Domesticated Plants in the Archaeological Record. In: M. Zeder, B. D., E. Emshwiller & B. Smith (eds.), *Documenting domestication. New genetic and archaeological paradigms*. California: University of California Press, 15-24.
- Smith, C., 1967. Plant remains. In: D.S. Byers (ed.), *The prehistory of the Tehuacan valley*. Austin: University of Texas Press, 220-254.

- Smith, C., 1980. Plant remains from Guitarrero Cave. In: T. Lynch (ed.), *Guitarrero Cave: early man in the Andes*. New York: Academic Press, 87-119.
- Spinden, H.J., 1917. The origin and distribution of agriculture in America. *Proceedings of the 19th International Congress of Americanists (1915)*. Washington DC, 269-276.
- Spooner, D.M., Mclean, K., Ramsay, G., Waugh, R. and Bryan, G.J., 2005. A single domestication for potato based on multilocus amplified fragment length polymorphism genotyping. *Proceedings of the National Academy of Sciences* 102(41), 14694-14699.
- Stahl, A.B., 1989. Plant food processing: implications for dietary quality. In: D.R. Harris & G.C. Hillman (eds.), *Foraging and farming: the evolution of plant exploitation*. London: Unwin-Hyman, 171-196.
- Staller, J., 2003. An Examination of the Palaeobotanical and Chronological Evidence for an Early Introduction of Maize (*Zea mays* L.) into South America: A Response to Pearsall. *Journal of Archaeological Science* 30(3), 373-380.
- Staller, J., 2006a. La domesticación de paisajes: ¿Cuáles son los componentes primarios del Formativo? *Estudios Atacameños* 32, 43-57.
- Staller, J., 2006b. The social, symbolic, and economic significance of *Zea mays* L. in the Late Horizon Period. In: J. Staller, R. Tykot & B.F. Benz (eds.), *Histories of maize: multidisciplinary approaches to the prehistory, linguistics, biogeography, domestication and evolution of maize*. Amsterdam: Elsevier, 449-465.
- Staller, J., 2010. *Maize cobs and cultures: history of Zea mays* L. Berlin: Springer.
- Staller, J. and Thompson, R., 2000. Reconsiderando la introducción del maíz en el Occidente de América del Sur. *Bulletin de l'Institut Francais d'Études Andines* 30(1), 123-156.
- Staller, J. and Thompson, R., 2002. A Multidisciplinary Approach to Understanding the Initial Introduction of Maize into Coastal Ecuador. *Journal of Archaeological Science* 29(1), 33-50.

- Stehberg, R., 1974. El complejo estructural de Guatín. *Estudios Atacameños* 2, 37-55.
- Stephens, S.G. and Moseley, M., 1973. Cotton Remains from Archeological Sites in Central Coastal Peru. *Science* 180(4082), 186-188.
- Stothert, K., 1985. The Preceramic Las Vegas Culture of Coastal Ecuador. *American Antiquity* 50(3), 613-637.
- Stovel, E., 2008. Interaction and social fields in San Pedro de Atacama, Northern Chile. In: H. Silverman & W. Isbell (eds.), *Handbook of South American Archaeology*. New York: Springer, 979-1002.
- Strömberg, C., 2007. Can slide preparation methods cause size biases in phytolith assemblages? Results from a preliminary study. In: M. Madella & D. Zurro (eds.), *Plants, people and places: recent studies in phytolith analysis*. Oxford: Oxbow, 1-12.
- Tamblay, J.A., 1990. Aspectos del proceso de formación del sitio arqueológico. Unpublished undergraduate thesis, Universidad de Chile.
- Tapia, M., 2000. *Cultivos Andinos subexplotados y su aporte a la alimentación*. Santiago: Oficina Regional de la FAO para América Latina y el Caribe.
- Tarragó, M., 1968. Secuencias culturales de la etapa Agroalfarera de San Pedro de Atacama (Chile). *Actas y Memorias del XXXVII Congreso Internacional de Americanistas*. Mar del Plata, Buenos Aires, 119-145.
- Tarragó, M., 1980. El proceso de agriculturización en el Noroeste Argentino, zona Valliserrana y sus relaciones con regiones vecinas. *Actas del V Congreso de Arqueología Nacional Argentina*. Instituto de Investigaciones Arqueológicas y Museo, Universidad de San Juan, 181-217.
- Tarragó, M., 1984. La historia de los pueblos circumpuneños en relación con el altiplano y los Andes Meridionales. *Estudios Atacameños* 7, 93-104.

- Tarragó, M., 1989. Contribución al conocimiento arqueológico de las poblaciones de los oasis de San Pedro de Atacama en relación con los otros pueblos puneños, en especial el sector septentrional del valle Calchaqui. Unpublished PhD thesis, Universidad Nacional de Rosario.
- Terrell, J.E., Hart, J.P., Barut, S., Cellinese, N., Curet, A., Denham, T., Kusimba, C., Latinis, K., Oka, R., Palka, J., Pohl, M.E., Pope, K.O., Williams, P.R., Haines, H. and Staller, J.E., 2003. Domesticated landscapes: the subsistence ecology of plant and animal domestication. *Journal of Archaeological Method and Theory* 10(4), 323-368.
- Therin, M., 1998. The movement of starch grains in sediments. In: R. Fullagar (ed.), *A closer look: recent Australian studies of stone tools*. Sydney: University of Sydney, 61-72.
- Therin, M., Fullagar, R. and Torrence, R., 1999. Starch in sediments: a new approach to the study of subsistence and land use in Papua New Guinea. In: C. Gosden & J. Hather (eds.), *The prehistory of food: appetites for change*. London; New York: Routledge, 427-451.
- Thomas, C., Benavente, A., Cartajena, I. and Contreras, L., 2002. Una secuencia de fechados por termoluminiscencia para la localidad de Chiu-Chiu: sitios Chiu Chiu 273 y 275. *Boletín de la Sociedad Chilena de Arqueología* 33/34, 84-89.
- Thomas, C., Benavente, A., Cartajena, I. and Serracino, G., 1995. Topater, un cementerio temprano: una aproximación simbólica. *Hombre y Desierto* 9, 159-170.
- Tieszen, L.L. and Chapman, M., 1992. Carbon and nitrogen isotopic status of the major marine and terrestrial resources in the Atacama desert of northern Chile. *Proceedings of the First World Congress on Mummy Studies*. Cabildo de Tenerife: Museo Arqueológico y Etnográfico de Tenerife, 409-426.
- Tieszen, L.L. and Fagre, T., 1993. Effect of diet quality and composition on the isotopic composition of respiratory CO₂, bone collagen, bioapatite, and soft tissues. In: B. Lambert & G. Grupe (eds.), *Prehistoric human bone: archaeology at the molecular level*. Berlin: Springer, 121-155.

- Timothy, D.H., 1961. *Races of maize in Chile*. Washington: National Academy of Sciences-National Research Council.
- Torres-Rouff, C., Pestle, W.J. and Gallardo, F., 2012. Eating Fish in the Driest Desert in the World: Osteological and Biogeochemical Analyses of Human Skeletal Remains from the San Salvador Cemetery, North Chile. *Latin American Antiquity* 23(1), 51-69.
- Towle, M., 1961. *The ethnobotany of pre-Columbian Peru*. Chicago: Aldine.
- Tsartsidou, G., Lev-Yadun, S., Albert, R.-M., Miller-Rosen, A., Efstratiou, N. and Weiner, S., 2007. The phytolith archaeological record: strengths and weaknesses evaluated based on a quantitative modern reference collection from Greece. *Journal of Archaeological Science* 34(8), 1262-1275.
- Tucker, B., 2006. A future discounting explanation for the persistence of a mixed foraging-horticulture strategy among the Mikea of Madagascar. In: D. Kennett & B. Winterhalder (eds.), *Behavioral ecology and the transition to agriculture*. London: University of California Press, 22-40.
- Twiss, P.C., Suess E. and Smith R.M., 1969. Morphological Classification of Grass Phytoliths *Soil Science Society of America Proceedings* 33, 109-115.
- Tykot, R., 2004. Stable isotopes and diet: you are what you eat. In M. Martini, M. Milazzo & M. Piacentini (eds.) *Proceedings of the International School of Physics "Enrico Fermi" Course CLIV*. Amsterdam: IOS Press.
- Tykot, R., Falabella, F., Planella, M.T., Aspillaga, E., Sanhueza, L. and Becker, C., 2009. Stable isotopes and archaeology in central Chile: methodological insights and interpretative problems for dietary reconstruction. *International Journal of Osteoarchaeology* 19(2), 156-170.
- Tykot, R. and Staller, J., 2002. The Importance of Early Maize Agriculture in Coastal Ecuador: New Data from La Emerenciana. *Current Anthropology* 43(4), 666-677.

- Ugent, D., Dillehay, T. and Ramírez, C., 1982a. Potato remains from a Late Pleistocene settlement in southcentral Chile. *Economic Botany* 41(1), 17-27.
- Ugent, D., Pozorski, S. and Pozorski, T., 1982b. Archaeological Potato Tuber Remains from the Casma Valley of Peru. *Economic Botany* 36(2), 182-192.
- Ugent, D., Pozorski, S. and Pozorski, T., 1984. New Evidence for Ancient Cultivation of *Canna edulis* in Peru. *Economic Botany* 38(4), 417-432.
- Ugent, D., Pozorski, S. and Pozorski, T., 1986. Archaeological Manioc (*Manihot*) from Coastal Peru. *Economic Botany* 40(1), 78-102.
- Uhle, M., 1913. Los indios atacameños. *Revista Chilena de Historia y Geografía* 9(5), 105-111.
- Uhle, M., 1917. *Los aborígenes de Arica*. Santiago: Imprenta Universitaria.
- Uribe, M., 2003. *La cerámica arqueológica del sitio Tulan-54: análisis tipológico y depositacional de un sitio Formativo Temprano del Salar de Atacama*. Proyecto Fondecyt 1020316. Unpublished report.
- Uribe, M., 2006. Sobre cerámica, su origen y complejidad social en los Andes del Desierto de Atacama, norte de Chile. In: H. Lechtman (ed.), *Esferas de interacción prehispánicas y fronteras nacionales modernas: Los Andes Sur Centrales*. Lima: Instituto de Estudios Peruanos, 449-502.
- Uribe, M. and Ayala, P., 2004. La alfarería de Quillagua en el contexto Formativo del Norte Grande de Chile (1.000 a.C. - 500 d.C.). *Chungara* 36(2), 585-597.
- Valero Garcés, B., Grosjean, M., Schwalb, A., Geyh, M., Messerli, B. and Kelts, K., 1996. Limnology of Laguna Miscanti; evidence for mid to late Holocene moisture changes in the Atacama Altiplano (Northern Chile). *Journal of Paleolimnology* 161-21.
- Vavilov, N., 1992 [1940]. *The origin and geography of cultivated plants*. Cambridge: Cambridge University Press.

- Vidal, A., 2007. Patrones de uso de los recursos vegetales durante el periodo Formativo (1000aC-500dC) en San Pedro de Atacama: oasis y quebradas. Unpublished undergraduate thesis, Universidad de Chile.
- Villagrán, C. and Castro, M., 2004. *Ciencia indígena de los Andes del norte de Chile*. Santiago: Editorial Universitaria.
- Villagrán, C. and Castro, V., 1997. Etnobotánica y manejo ganadero de las vegas, bofedales y quebradas en el Loa superior, Andes de Antofagasta, Segunda Región, Chile. *Chungara* 29(2), 275-304.
- Villagrán, C., Castro, V. and Sánchez, G., 1998a. Etnobotánica y percepción del paisaje en Caspana (Provincia de El Loa, Región de Antofagasta, Chile): ¿Una cuña atacameña en el Loa Superior? *Estudios Atacameños* 16, 107-170.
- Villagrán, C., Castro, V., Sánchez, G., Romo, M., Latorre, C. and Hinojosa, L., 1998b. La tradición surandina del desierto: Etnobotánica del área del Salar de Atacama (Provincia de El Loa, Región de Antofagasta, Chile). *Estudios Atacameños* 16, 7-105.
- Villagrán, C., Kalin-Arroyo, M. and Marticorena, C., 1983. Efectos de la desertización en la distribución de la flora andina de Chile. *Revista Chilena de Historia Natural* 56, 137-157.
- Villagrán, C., Romo, M. and Castro, V., 2003. Etnobotánica del sur de los Andes de la Primera Región de Chile: un enlace entre las culturas altiplánicas y las de quebradas altas del Loa superior. *Chungara* 35(1), 73-124.
- Wadley, L. and Lombard, M., 2007. Small things in perspective: the contribution of our blind tests to micro-residue studies on archaeological stone tools. *Journal of Archaeological Science* 34(6), 1001-1010.
- Wadley, L., Lombard, M. and Williamson, B., 2004. The first residue analysis blind tests: results and lessons learnt. *Journal of Archaeological Science* 31(11), 1491-1501.

- Whaley, O., Orellana, A., Pérez, E., Tenorio, M., Quinteros, F., Mendoza, M. and Pecho, O., 2010. *Plantas y Vegetación de Ica, Perú– Un recurso para su restauración y conservación*-. London: Royal Botanical Gardens, KEW.
- Wheeler, J., 1995. Evolution and Present Situation of the South American Camelidae. *Biological Journal of the Linnean Society* 54(3), 271-195.
- Wheeler, J., Pires-Ferreira, E. and Kaulicke, P., 1977. Domesticacion en los Andes Centrales durante el Periodo Preceramico: un modelo. *Journal de la Societe des Americanistes* 14, 155-165.
- Whitaker, T., 1983. Cucurbits in Andean Prehistory. *American Antiquity* 48(3), 576-585.
- White, C., Longstaffe, F. and Schwarcz, H.P., 2006. Social directions in the isotopic anthropology of maize in the Maya Region. In: J. Staller, R. Tykot & B.F. Benz (eds.), *Histories of maize: multidisciplinary approaches to the prehistory, linguistics, biogeography, domestication and evolution of maize*. Amsterdam: Elsevier, 143-159.
- Whitehead, W.T., 2006. Redefining plant use at the Formative site of Chiripa in the southern Titicaca Basin. In: W. Isbell & H. Silverman (eds.), *Andean Archaeology III: North and South*. New York: Springer, 258-278.
- Whitehead, W.T., 2007. Exploring the Wild and Domestic: Paleoethnobotany at Chiripa, a Formative Site in Bolivia. Unpublished PhD thesis, University of California, Berkeley.
- Willey, G. and Sabloff, J.A., 1980. *A history of American archaeology*. San Francisco: W.H. Freeman and Co.
- Willey, G.R. and Phillips, P., 1958. *Method and theory in American archaeology*. Chicago: University of Chicago Press.
- Williamson, B., 2006. Investigation of potential contamination on stone tools. In: R. Torrence & H. Barton (eds.), *Ancient starch research*. Walnut Creek: Left Coast Press, 89-90.

- Wilson, H., 1988. Allozyme Variation and Morphological Relationships of *Chenopodium hircinum* (s.l.). *Systematic Botany* 13(2), 215-228.
- Winterhalder, B. and Kennet, D., 2006. Behavioral ecology and the transition from hunting and gathering to agriculture. In: D. Kennet & B. Winterhalder (eds.), *Behavioral ecology and the transition to agriculture*. London: University of California Press, 1-21.
- Winterhalder, B. and Kennett, D., 2009. Four neglected concepts with a role to play in explaining the origins of agriculture *Current Anthropology* 50(5), 645-648.
- Wollstonecroft, M., 2007. Post-harvest intensification in Late Pleistocene Southwest Asia: plant food processing as a critical variable in Epipalaeolithic subsistence and subsistence change. Unpublished PhD thesis, University College London.
- Wollstonecroft, M., 2009. Harvesting experiments on the clonal helophyte sea club-rush (*Bolboschoenus maritimus* (L.) Palla): an approach to identifying variables that may have influenced hunter-gatherer resource selection in Late Pleistocene Southwest Asia. In: A. Fairbairn & E. Weiss (eds.), *From foragers to farmers; papers in honour of Gordon C. Hillman*. Oxford: Oxbow Books, 127-139.
- Wollstonecroft, M., Ellis, P., Hillman, G.C. and Fuller, D., 2008. Advances in plant food processing in the Near Eastern Epipalaeolithic and implications for improved edibility and nutrient bioaccessibility: an experimental assessment of *Bolboschoenus maritimus* (L.) Palla (sea club-rush). *Vegetation History and Archaeobotany* 17(1), 19-27.
- Wollstonecroft, M. and Erkal, A., 2003. Summary of plant processing experiments at Çatalhöyük. *Çatalhöyük 2003 archive report*.
- Wollstonecroft, M., Hroudová, Z., Hillman, G.C. and Fuller, D., 2011. *Bolboschoenus glaucus* (Lam.) S.G. Smith, a new species in the flora of the ancient Near East. *Vegetation History and Archaeobotany* 20(5), 459-470.
- Wright, H.E., 1993. Environmental Determinism in Near Eastern Prehistory. *Current Anthropology* 34(4), 458-469.

- Wright, K., 1992. A classification system for ground stone tools from the prehistoric Levant. *Paléorient* 18(2), 53-81.
- Wright, K., 1993. Early Holocene Ground Stone Assemblages in the Levant. *Levant* 25(1), 93-111.
- Wright, K., 1994. Ground-Stone Tools and Hunter-Gatherer Subsistence in Southwest Asia: Implications for the Transition to Farming. *American Antiquity* 59(2), 238-263.
- Wright, K., Critchley, P., Garrard, A., Baird, D., Bains, R. and Groom, S., 2008. Stone Bead Technologies and Early Craft Specialization: Insights from Two Neolithic Sites in Eastern Jordan. *Levant* 40(2), 131-165.
- Wright, M., 1993. Simulated Use of Experimental Maize Grinding Tools from Southwestern Colorado. *Kiva* 58(3), 345-355.
- Yacobaccio, H., 2001. Cazadores complejos y domesticación de camélidos. In: G.L. Mengoni, D. Olivera & H. Yacobaccio (eds.), *El uso de los camélidos a través del tiempo*. Buenos Aires: Ediciones del Tridente, 261-282.
- Yacobaccio, H., 2003. Procesos de intensificación y de domesticación de camélidos en los Andes Centro-Sur. In T.I.D. Decama (ed.) *III Congreso Mundial sobre Camélidos*. Potosí: UNEPACA, 211-216.
- Yacobaccio, H., 2004. Social Dimensions of Camelid Domestication in the Southern Andes. *Anthropozoologica* 39(1), 237-247.
- Yacobaccio, H., 2006. Social complexity in South Andean hunting-gathering society. *Change in the Andes: origins of social complexity, pastoralism and agriculture*. Liège, Belgium: BAR International Series.
- Yacobaccio, H., 2007. Andean camelid herding in the South Andes: ethnoarchaeological models for archaeozoological research. *Anthropozoologica* 42(2), 143-154.

- Yacobaccio, H., Morales, M.R. and Samec, C.T., 2009. Towards an isotopic ecology of herbivory in the Puna ecosystem: new results and patterns on Lama glama. *International Journal of Osteoarchaeology* 19(2), 144-155.
- Yacovleff, E. and Herrera, F.L., 1935. *El mundo vegetal de los antiguos Peruanos*. Lima: Imprenta del Museo Nacional.
- Zapater, H., 1976-77. Cinco relaciones sobre San Pedro Atacama. *Instituto Geografico Universidad Católica de Chile* 549-63.
- Zárate, S., 1997. Domestication of Cultivated Leucaena (Leguminosae) in Mexico: The Sixteenth Century Documents. *Economic Botany* 51(3), 238-250.
- Zárate, S., 2000. The Archaeological Remains of Leucaena (Fabaceae) Revised. *Economic Botany* 54(4), 477-499.
- Zeder, M.A., 2006. Central questions in the domestication of plants and animals. *Evolutionary Anthropology* 15(3), 105-117.
- Zohary, D. and Hopf, M., 1988. *Domestication of plants in the old world: The origin and spread of cultivated plants in west Asia, Europe, and the Nile Valley*. Oxford and New York: Clarendon Press.